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EFFECT OF TEMPERATURE AERATION AND HUMIDITY ON JONATHAN-SPOT AND SCALD OF APPLES IN STORAGE [1]

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INTRODUCTION

As the public becomes more critical in regard to foods, the troubles which affect the appearance of fruit but do not completely destroy it are brought into greater prominence, both from a pathological and an economic point of view. These troubles are of importance not only because of their damaging effects on the appearance of the fruit but also because of the part they may play in paving the way for the entrance of various rot-producing fungi. The present paper is a report on Jonathan-spot and scald of apples (*Malus sylvestris*), including a study of their relation to rot infection and the modifying effects of storage conditions and maturity of fruit.

EXPERIMENTAL APPARATUS

The apparatus used in the experiments has been fully described in an earlier publication (3).[2] The fruit was held in galvanized-iron boxes which had a 3-inch air space between them and the outer insulating walls of the chambers. The brine pipes were located outside of these metal boxes. This arrangement made it possible to keep the air in the inner boxes free from the drying effects of the brine pipes and thus to maintain higher humidities than could have been otherwise secured. The air in the inner boxes was circulated by means of fans. Where high humidity was desired, the air was fanned over pans containing water and saturated sponges; to obtain lower humidities it was circulated over calcium chlorid and lime. A record of the temperature and the humidity was kept by means of thermographs and hygrographs placed in the middle of the boxes and by wet and dry bulb thermometers in front of the fans.

[1] Studies in Fruit Rots and Spots, II. [2] Reference is made by number to "Literature cited," p. 316-317.

JONATHAN-SPOT

DESCRIPTION

Jonathan-spot (19) is a name applied to superficial black or brown spots of the apple that are especially common on the Jonathan variety. In the early stages of the disease only the superficial color bearing cells are involved, and the spots are seldom more than 2 mm. in diameter. Later the spots may enlarge to a diameter of 3 to 5 mm., become slightly sunken, and spread down into the tissue of the apples to a considerable depth. In the later stages of the disease rot fungi are often present, species of Alternaria being particurlarly common. The spots usually occur at lenticels.

RELATION OF JONATHAN-SPOT TO APPLE ROTS

Scott and Roberts (19) have pointed out that a apecies of Alternaria is often present in late stages of Jonathan-spot, and Cook and Martin (6) have found that a species of Alternaria is almost universally associated with Jonathan-spot as it occurs in New Jersey. The writers' experiments and observations indicate that fungi are not present in the initial stages of the disease, but that Jonathan-spots often serve as points of infection for species of Alternaria and other apple-rot fungi. In addition to repeated observations on this point, inoculation experiments were made to determine the influence of Jonathan-spot upon the susceptibility of the fruit to rot infection. A box of western Jonathan apples purchased on the Washington market were separated into two lots, one affected with Jonathan-spot and the other free from it. The apples of the two lots were practically alike in size and color. Part of the spot-free apples were punctured with a platinum needle, two punctures being made on each apple. All of the apples were washed in water that carried a heavy suspension of the spores of rot fungi, and the fruit was then stored in moist chambers at 15° C. The following results were obtained at the end of two weeks.

TABLE I.—*Effect of Jonathan-spot on infection by apple rots*

Fungus.	Condition of apples used.			Total number of infections on apples—		
	Sound.	Spotted.	Punctured.	With Jonathan-spot.	Free from Jonathan-spot.	With a total of eight needle punctures.
Alternaria sp.	6	6	4	12	0	1
Penicillium expansum	6	6	4	1	2	7
Sclerotinia cinerea	6	6	4	0	0	1
No fungus	6	6	4	1	0	0

The results show that apples affected with Jonathan-spot are especially susceptible to infection with *Alternaria* sp.

EFFECT OF TEMPERATURE ON JONATHAN-SPOT

Scott and Roberts (19) found that apples stored in a moderately cool basement developed much more Jonathan-spot than similar fruit held in commercial cold storage.

In 1915 and again in 1916 the writers carried out experiments to obtain further data in regard to the factors influencing the development of the disease. The fruit used in the experiments was shipped by express direct from the orchard to the laboratory, so that there was never a delay of more than four days after picking before the apples were placed under the various storage conditions. The fruit was always carefully sorted so that the apples placed at the various temperatures or humidities that were to be compared would be as nearly alike as possible in size, color, and maturity. This was accomplished by selecting a number of apples that were similar in all respects and distributing them one each in the containers that were to be placed under the different conditions and repeating the process until the desired number of apples was obtained. All the apples were Jonathan and all were free from Jonathan-spot at the beginning of the experiments. The apples used in the experiments reported in figure 1 were from West Virginia, those of figure 7 from New Jersey, and those used in the other experiments from Pennsylvania. The apples used in the experiments recorded in figure 6 averaged more than 3 inches in diameter, while those used in the other experiments averaged about 2½ inches in diameter. In the former cases, 8 apples were used for each temperature or storage condition and in the latter, 10 to 15 apples for each condition.

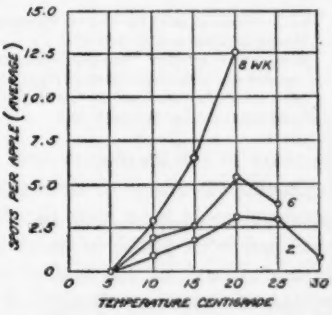

FIG. 1.—Graphs showing the effect of temperature on Jonathan-spot at the end of 2, 6, and 8 weeks. The apples were stored in moist chambers with moist filter paper added. The experiment was started on November 6, 1915.

The results obtained are shown in figures 1 to 8, inclusive. In all the figures the perpendiculars show the average number of spots per apple and the base lines the centigrade temperature.[1] In some of the experiments (as noted in the figures) a warm laboratory was used for the 25° C. temperature. This room temperature was not constant and averaged less than 25°. All the other temperatures were carefully controlled.

A study of the curves in the different figures shows that the amount of Jonathan-spot increased with a rise in temperature up to 20°, but that

[1] Temperature equivalents.

°C.	°F.	°C.	°F.	°C.	°F.
0	32	15	59	25	77
5	41	20	68	30	86
10	50				

the disease made practically no development at 30°. The increase in the disease between 10° and 15° was very striking, and it is of special interest to note that in most cases Jonathan-spot was held practically in check at 5° as well as at 0°. It was thought possible that the spots might be present in an incipient form at the lower temperatures and that they would make a rapid development upon removal to warmer temperatures, but experiments made to test this point gave negative results in all cases.

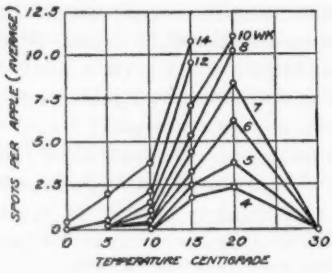

FIG. 2.—Graphs showing the effect of temperature on Jonathan-spot at the end of 4, 5, 6, 7, 8, 10, 12, and 14 weeks. The apples were well matured and were stored in moist chambers with moist filter paper added. The experiment was started on October 6, 1916.

The failure of the disease to develop at 30° indicates that its occurrence can not be primarily due to the presence of *Alternaria* sp., as has been suggested by Cook and Martin (6, 7), since it has been shown by the writers in an earlier publication (3) that *Alternaria* sp. makes a more vigorous growth at 30° than at any lower temperature.

The importance of uniform temperature in the keeping of fruit has often been emphasized. An experiment was made to determine the effect that fluctuations in temperature would have upon the development of Jonathan-spot. Apples that had been placed in moist chambers were moved back and forth from 5° to 25° at the end of each second day, and the results were compared with those obtained at constant temperatures. It was found that slightly less disease developed on the fruit exposed to the different temperatures than on that kept at the average temperature of 15°. Moving the moist chamber to a different temperature naturally favored an exchange of air, and it is possible that this partial aeration of the container may have had some tendency to decrease the disease. However this may have been, the results indicated no harmful effects from fluctuating temperatures, so far as Jonathan-spot was concerned.

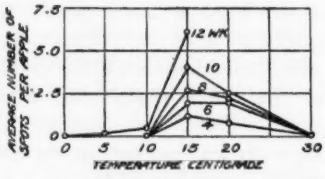

FIG. 3.—Graphs showing the effect of temperature on Jonathan-spot at the end of 4, 6, 8, 10, and 12 weeks. The apples were well matured and of the same lot as those of figure 2 but were stored in open containers in air that was gently stirred and that had a relative humidity of 85 to 95 per cent. The experiment was started on October 6, 1916.

The various experiments make it evident that temperature plays an extremely important part in the development of Jonathan-spot. It would be impossible to state just whan physiological processes have been most concerned in the results, but it is evident that the effects are of a cumulative nature. The disease has not usually made much progress during the first month of storage, but after that time the number of spots

have increased in a very gradual manner over a period of one or two months.

EFFECT OF AERATION AND HUMIDITY ON JONATHAN-SPOT

In most of the temperature experiments part of the fruit was placed in moist chambers and part in wire baskets or other open containers. The tops of the moist chambers fitted loosely, nearly always leaving cracks of 0.5 mm. or more, yet preventing a free circulation of air. The apples in the open containers were freely exposed to the air of the boxes, which was kept in circulation by fans. Anemometer tests showed that the movement of the air was in no case as rapid as ½ mile per hour. Gas analyses reported later under the head of "Apple-scald" (p. 300) showed that the amount of carbon dioxid in the free air of the boxes was little above normal, while that in the moist chambers was sufficiently high to have a distinctly depressive effect upon respiration.

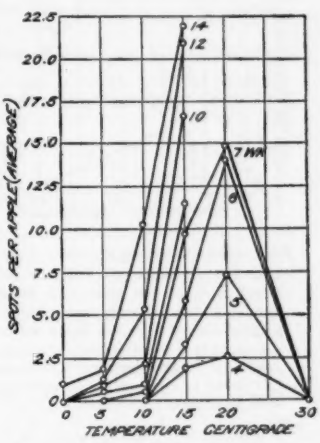

FIG. 4.—Graphs showing the effect of temperature on Jonathan-spot at the end of 4, 5, 6, 7, 8, 10, 12, and 14 weeks. The apples were of the same lot as those of figure 2 but were greener. They were stored in moist chambers with moist filter paper added. The experiment was started on October 6, 1916.

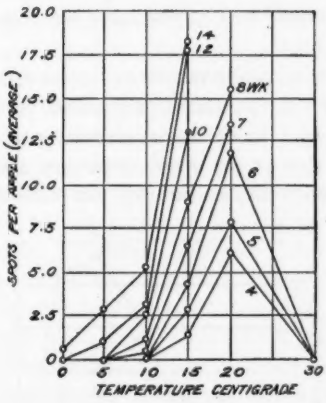

FIG. 5.—Graphs showing the effect of temperature on Jonathan-spot at the end of 4, 5, 6, 7, 8, 10, 12, and 14 weeks. The apples were of the same lot as those of figures 2 and 4 but were greener than the former and riper than the latter. They were stored in moist chambers with moist filter paper added. The experiment was started on October 6, 1916.

The effects of aeration and humidity upon Jonathan-spot are brought out in figures 6 and 8. In figure 6 curve A shows the amount of the disease developed in moist chambers to which wet filter paper had been added, and curve B the amount developed in the open containers. The air in the former case was practically saturated, while in the latter case that at 10° had a relative humidity of 55 to 70 per cent and that at 25° was probably still drier. The experiments recorded in figure 8 were more carefully controlled. Curve C shows the amount of Jonathan-

spot developed at the various temperatures in moist chambers to which wet filter paper had been added, and curve D the amount developed in open containers in an atmosphere having a relative humidity that ranged from 85 to 95 per cent, and usually stood slightly above 90 per cent. The weekly contrasts obtained under these two conditions of storage are given in figures 2 and 3. At 15° a second box was maintained in which the relative humidity ranged from 65 to 75 per cent, and usually stood at 70 per cent. Under this condition the fruit became decidedly withered by the end of the second month. The rate at which Jonathan-spot developed on the apples in the open containers in this dry box was practically the same as that in the more humid box at the same temperature (fig. 3).

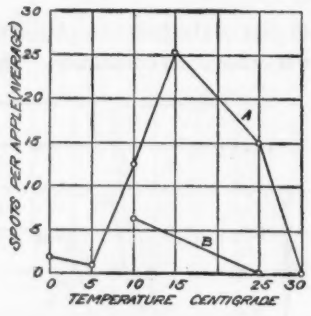

FIG. 6.—Graphs showing the effect of aeration and humidity on Jonathan-spot. Graph A shows the amount of disease developed at the different temperatures in moist chambers and graph B the amount developed in open containers. The apples were large. The experiment was started on October 16, 1915, and the above records were taken three weeks later.

A study of the results in figures 2, 3, 6, and 8 shows that the amount of Jonathan-spot in the moist chambers was usually more than twice as great as that in the open containers, and that this held not only for all the temperatures but for the various periods of storage. The results seem to leave no question that the storage in moist chambers favored the development of the disease, but the nature of the experiment makes it difficult to estimate the relative importance of aeration and humidity. In the one experiment reported above in which the effect of a humidity of 70 per cent was compared with that of a humidity of 90 per cent under similar conditions of aeration, the data furnished no evidence that the amount of moisture in the air had any influence upon the development of Jonathan-spot. In so far as the results of a single experiment can be relied upon, evidence is furnished that the striking contrasts obtained between storage in moist chambers and storage in the open containers are due to differences in aeration rather than to differences in humidity. This interpretation of the results would be

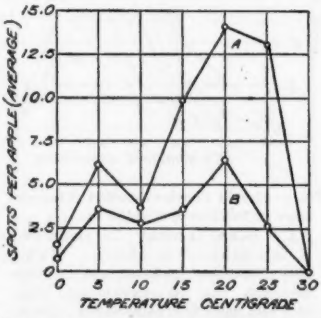

FIG. 7.—Graphs showing the effect o the maturity of fruit on Jonathan-spot. Graph A shows the amount of disease on the green fruit and graph B the amount on the ripe fruit. The apples were stored in moist chambers with moist filter paper. The experiment was started on October 26, 1915, and the above records were taken five weeks later.

entirely in harmony with the temperature responses and the cumulative nature of the disease. The question of aeration and humidity will be more fully discussed in connection with the results on apple-scald.

EFFECT OF MATURITY OF FRUIT ON JONATHAN-SPOT

Experiments were made to determine the effect of the maturity of fruit upon its susceptibility to Jonathan-spot. Jonathan apples of a particular picking and of a particular lot were divided into two classes that were as nearly alike as possible as to size of fruit, but one contained apples on which the ground color was decidedly more yellow than the other. There was usually also a larger blush area on the former than on the latter. The method of selection has been described on page 299. The apples of the two lots were placed in moist chambers and distributed at the different temperatures already mentioned. The results of the experiments are shown in figures 7 and 8. In figure 7 curve A shows the amount of disease developed on the green fruit and curve B the amount on the ripe fruit; in figure 8 curve A the disease on the green fruit and curve C the disease on the ripe fruit under like conditions. Further contrasts may be obtained by comparing the weekly development of Jonathan-spot on the ripe fruit, as shown in figure 3 with the weekly development on the green fruit, as shown in figure 6. In both the sets of experiments and at all the different temperatures the green fruit showed a greater susceptibility to Jonathan-spot than the ripe fruit.

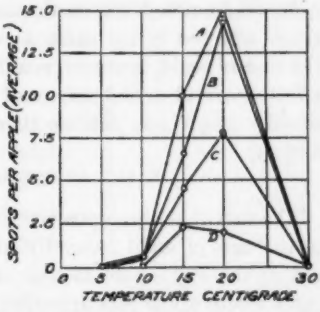

FIG. 8.—Graphs showing the effect of maturity of fruit and of aeration and humidity on Jonathan-spot. Graph A shows the amount of disease developed at the different temperatures on the greenest fruit of the particular lot, graph B the amount developed on the fruit that was somewhat riper, and graphs C and D the amount on the ripest fruit. The apples of graph D were stored in open containers and the others of the experiment in moist chambers. The experiment was started on October 6, 1916, and the above records were taken seven weeks later. See figures 2, 3, 4, and 5.

The color of the spots that occurred on the lighter skin surfaces of the fruit was a lighter brown than that of the spots on the blush surfaces. The green fruit had less color than the ripe and consequently a relatively larger percentage of the light-brown spots. No clear-cut distinction could be drawn between the two kinds of spots, as the color of the one gradually shaded into that of the other, and they were exactly alike in other characteristics.

It is the general opinion of persons who have made orchard observations on Jonathan-spot that the disease is worst on the ripest fruit. The above experiments show that under certain storage conditions green fruit is more susceptible to the disease than ripe fruit, but it does not

necessarily follow that the spots that develop under orchard conditions would obey the same law.

APPLE-SCALD

"Scald" is a term applied to a superficial browning that often occurs on apples in storage. Usually only the five or six surface layers of cells that form the color-bearing tissue of the apple are affected, but in aggravated cases the trouble may extend entirely through the firmer skin layer of the apple into the large isodiametric cells of the pulp. In such cases the flesh becomes soft, brown, and rotlike, and the trouble is sometimes spoken of as "deep-scald." Deep-scald has been of more common occurrence on York Imperial than on Grimes.

It will be noted that in the earlier and more typical cases of scald the tissue affected is the same as with Jonathan-spot. The skin color in the case of scald, however, is a light rather than a dark brown, the areas affected are always larger, and the demarcation between diseased and healthy tissue less definite than in the case of Jonathan-spot (Pl. 32 and 33).

SCALD AS A SOURCE OF ROT INFECTION

The fact that the protective skin layers of the apple are broken down in the case of scald naturally suggests the importance of the disease in paving the way for the attacks of fungi. The writers had often observed cases where apple rots appeared to follow scald, but it seemed desirable to make an experimental determination of the relation of scald to rot infection. The test was made on Grimes apples that had been used in the aeration and humidity experiments reported later. The scalded fruit had been picked at the same time and stored at the same temperature as the unscalded, but had received poorer aeration. The apples were washed in heavy spore suspensions of the fungus in the manner already described in the rot experiments on Jonathan-spot. Ten scalded and ten scald-free apples were used with each fungus. The experiment was started on November 7. Table II shows the results obtained with *Glomerella cingulata* after two weeks, and with *Penicillium expansum* and *Sclerotinia cinerea* after three weeks.

TABLE II.—*Relation of apple-scald to infection by apple rot fungi*

Fungus.	Number of infections on—	
	Scalded apples.	Scald-free apples.
Glomerella cingulata	9	0
Penicillium expansum	10	1
Sclerotinia cinerea	8	0

The results indicate that the dead-skin areas produced by apple-scald furnish an excellent opportunity for attacks by the common rot fungi. According to the observations of the writers, *Alternaria* sp. is more likely to infect scalded tissue than any other rot-producing fungus. Unfortunately cultures of this fungus were not available for inoculation at the time of the above experiment. It will be recalled that Jonathan-spot tissue was found to be particularly susceptible to the attacks of *Alternaria* sp.

EFFECT OF TEMPERATURE ON APPLE-SCALD

Numerous experiments have been reported on the effect of temperature upon apple-scald. Powell and Fulton (17) found that prompt refrigeration was important in the prevention of apple-scald, but Greene (11) reported that holding the temperature high enough to permit the fruit to continue ripening delayed the appearance of scald and found that Grimes apples scalded much less when they were not stored immediately after picking. Some writers have reported that scald is worse in cold storage than in cellar storage, while others have found that the reverse condition apparently held.

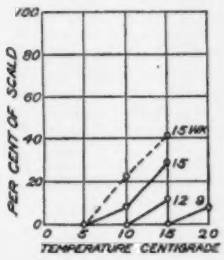

FIG. 9.—Graphs showing the effect of temperature on apple-scald at the end of 9, 12, and 15 weeks. The dotted graph shows the amount of scald 3 days after removal from storage at the end of the 15 weeks. The apples were Jonathan and the same as referred to in figures 2, 4, and 5 of the Jonathan-spot experiments. The results were similar for the different lots, and the average given is in the above graphs.

In the fall of 1915 and again in the fall of 1916 the writers carried out experiments to determine the effect of temperature on scald. The apparatus used in the experiments has already been described (p. 297). Great care was taken that the apples at the different temperatures should be alike in size and maturity (p. 299). Arkansas, Baldwin, Grimes, Jonathan, Northwestern, and York Imperial apples were used. The results obtained on the last three varieties are given in figures 9 to 16. The experiments made on the other varieties were not so complete nor the scald so bad, but the results were in agreement with those reported. In all of the figures the base line represents temperature centigrade and the perpendicular the per cent of scald. In obtaining records on the degree of scald the maximum scald that had been observed to occur on the variety was taken as 100 and the amount of scald in a particular case was measured by its relation to this standard. Both the area and the depth of the scald were considered. A record was made by two observers; and where differences occurred, the average was taken. The notes were made without reference to previous records. The amount of scald on the different apples at a particular temperature was remarkably uniform. In the early stages of scald at the higher temperature the apples took on a dry, russet appearance that was at first classed as distinct from the usual form

of scald; but this soon passed over into the solid brown coloration typical of scald at lower temperatures, and therefore seemed to require no separate classification. From 11 to 16 apples were used at each temperature in most of the experiments, but in the case of the results shown in figures 9 and 14, only 5 apples were used. Except where otherwise stated, the apples were in moist chambers.

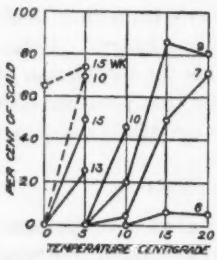

FIG. 10.—Graphs showing the effect of temperature on apple-scald at the end of 6, 7, 9, 10, 13, and 15 weeks. The dotted graphs show the amount of disease 3 days after removal from storage at the end of the given week. The apples were York Imperial from Quincy, Pa. They were picked about October 8 and the experiment was started on October 11, 1916.

The Jonathan showed less susceptibility to scald than the Grimes and York Imperial apples, but so far as temperature response is concerned, the results are so similar with the different varieties and in the different experiments that separate discussion is unnecessary.

In all of the experiments apples were placed at 30° C., as well as at the temperatures indicated in the various figures. In most cases it was found necessary to discard the apples at this temperature on account of internal breakdown before there had been time for the development of scald. The only exception to this is shown in figure 12 and was obtained with apples that were quite immature. The results indicate that a temperature of 30° is unfavorable to the development of scald.

Scald always started sooner at 20° than at 15°, but in most cases the contrasts in the amount of disease at the two temperatures soon disappeared, and with Grimes apples of figure 15 the fruit finally showed a greater degree of injury at 15° than at 20°. The contrasts between the results at 10° and 15° were very striking with York Imperial and Grimes, especially during the second month of storage. During the third month scald developed rapidly at 10°, soon producing decided contrasts between the results at this temperature and those at 5°. During the fourth month scald began to appear at 5°, and in the following month traces of the disease were evident at 0° on the more susceptible apples.

With the Jonathan apples the disease developed more slowly, usually making its appearance on this variety about a month later than on the Grimes and York Imperial.

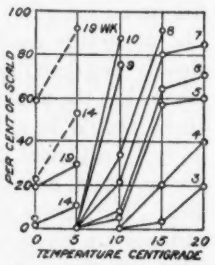

FIG. 11.—Graphs showing the effect of temperature on apple-scald at the end of 3, 4, 5, 6, 7, 8, 9, 10, 14, and 19 weeks. The dotted graphs show the amount of disease 3 days after removal from storage at the end of the given week. The apples were Grimes from Middletown, Va. They were picked on September 2 and the experiment was started on September 9, 1916.

The amount of scald developed at the lower temperatures did not become fully evident until the fruit had been removed from storage.

This was particularly true of apples at 0°. The dotted lines in figures 9 to 15, inclusive, show the results at the end of the given week, but after the fruit had stood for three days at laboratory temperature. Half of the fruit under the particular condition was removed in each case. A comparison of this data with that obtained before removal, as shown by the solid lines having the same numbers, makes it evident that the scald on apples at 5° may appear several times as bad after a few days of free exposure to warm air, and that apples at 0° may be rather badly scalded without showing it while remaining at that temperature. In some cases the Grimes had developed a latent scald at 0° by the end of 10 weeks, but the York Imperial failed to show any scald upon removal from storage at that time, and the Jonathan had none at either 0° or 5° upon removal at the end of 15 weeks.

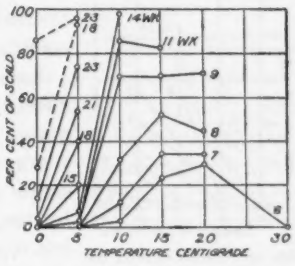

FIG. 12.—Graphs showing the effects of temperature on apple-scald at the end of 6, 7, 8, 9, 11, 14, 15, 18, 21, and 23 weeks. The dotted graphs show the amount 3 days after removal from storage at the end of the given week. The apples were Grimes from Vienna, Va. They were picked on August 10 and the experiment was started on August 11, 1916.

While the fruit at low temperatures showed a greater amount of scald upon removal, the nature of the temperature contrasts was not changed, the difference between the amount of disease at 0° and 5° usually being nearly as great after removal as before. The whole series of experiments has been consistent in showing that an increase in temperature is accompanied by an increase in rate of scald up to an optimum of 15° or 20°. The critical period for scald development appeared about a month earlier with each 5-degree rise in temperature.

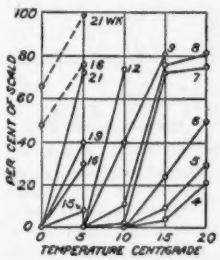

FIG. 13.—Graphs showing the effect of temperature on apple-scald at the end of 4, 5, 6, 7, 8, 9, 12, 15, 16, 19, and 21 weeks. The dotted graphs show the amount 3 days after removal from storage at the end of the given week. The apples were Grimes from the same orchard as those of figure 12, but were picked on August 28 and the experiment was started on August 29, 1916.

Experiments were made to determine whether the increase in disease upon removal from storage was due to the sudden change in temperature. York Imperial apples that had been held in commercial cold storage till the first of April were removed and divided into various lots that were distributed at temperatures of 0°, 5°, 10°, 15°, and 20°. Some of the apples were allowed to remain at each of these temperatures, while others were gradually moved to higher temperatures. At the end of 10 days practically no scald was evident at 0° and 5°, and only about half as much at 10° as at 15° and 20°. At this time all of the apples from the lower temperatures were removed to 20°. After two days at this temperature all of the fruit was scalded practically alike, regard-

less of the gradation of temperature it had passed through in removal. It was evident that the method of removal had little or no effect upon the production of the disease, and further proof was obtained of the ability of the lower temperatures to inhibit the development of the scald phenomena after the diseased condition had actually been produced.

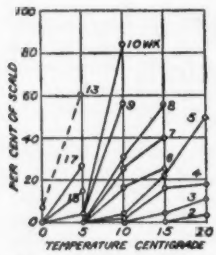

FIG. 14.—Graphs showing the effect of temperature on apple-scald at the end of 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, and 17 weeks. The dotted graphs show the amount 3 days after removal from storage at the end of the given week. The apples were Grimes from the same orchard as those of figures 12 and 13, but were picked on September 21 and the experiment was started on September 22.

Experiments were also made to determine the effect of fluctuating temperatures upon the development of scald. Palladine (16) found that sudden changes in temperature caused an increase in the amount of carbon dioxid given off by seedlings, but Blanc (1), on the other hand, has reported that when seedlings and plant parts were moved from one temperature to another the rate of respiration was a mean between the normal rates at the two temperatures.

Grimes apples of the same lot as reported in figure 11 were placed in moist chambers and moved from one temperature to another at intervals of two days. In one case the apples were moved back and forth from 5° to 20°. The amount of scald developed at the different times of recording was found to be slightly less than on similar apples at a constant temperature of 15°, and the moved apples "stood up" approximately the same length of time as those at 15°, both being discarded on November 6.

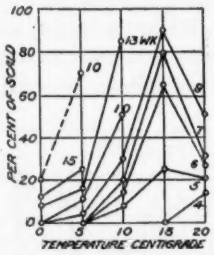

FIG. 15.—Graphs showing the effect of temperature on apple-scald at the different temperatures at the end of 4, 5, 6, 7, 9, 10, 13, and 15 weeks. The dotted graph shows the amount of disease 3 days after removal from storage at the end of the given week. The apples were Grimes of the same lot as those of figure 11, but had been in commercial cold storage from September 9 to October 16.

In a similar experiment with apples of the same lot the moist chambers were moved back and forth from 0° to 30°. The higher temperature was secured in a warm laboratory and not in a closed incubator. The apples developed no scald and "stood up" till November 20—as long as similar apples at a constant temperature of 10°. Two reasons can be offered for the absence of scald, one that better aeration was secured by leaving the moist chambers in the open laboratory a part of the time and the other that, as has already been pointed out, storage at a temperature of 30° is unfavorable to the development of scald. The fact that the apples "stood up" well in storage would emphasize the first hypothesis.

The results of the two experiments and of other similar experiments indicate that apples at a fluctuating temperature develop but little, if any, more scald than similar apples at an average but constant temperature.

EFFECT OF AERATION AND HUMIDITY ON APPLE-SCALD

There has been a great diversity of opinion as to the importance of ventilation in the development of scald. Powell and Fulton (17) found that paper wrappers did not reduce the amount of scald on apples, but that paraffin wrappers did. They further found that an atmosphere of moist oxygen favored the development of scald, while an atmosphere of nitrogen prevented it, at least during short periods of storage. Greene (11) reported that wrapping fruit retarded the ripening processes and delayed the appearance of scald.

Fulton (9) reported that extra wrappings on cartons of berries resulted in a decrease in the oxygen of the package and an increase in the carbon dioxid and caused the fruit to soften prematurely and take on a bad flavor. He found that these conditions were still more emphasized by storage in tightly stoppered glass bottles.

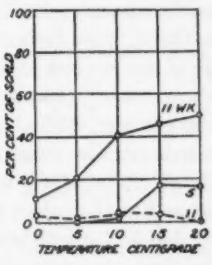

FIG. 16.—Graphs showing the effect of aeration and humidity on apple-scald. The solid graphs show the amount of scald developed in moist chambers at the end of 5 and 11 weeks and the dotted graph the amount in an open container. The apples were Grimes from cold storage. The experiment was started on November 6, 1915.

Hill (12) found that storing apples and peaches in either nitrogen or hydrogen resulted in a bleaching or browning of the skin and in the development of disagreeable flavors. Peaches stored in carbon dioxid developed similar conditions, but a more nauseating flavor. The peaches in hydrogen and those in nitrogen became soft, but those in carbon dioxid did not. He thought that the firmness of the fruit in the latter case was due to the fact that the gas decreased the hydrolysis of pectose.

Thatcher (21) stored apples in various gases. He found that in an atmosphere of air or of oxygen the apples became visibly overripe within four weeks, that in hydrogen or in nitrogen they did not soften so rapidly, but soon became discolored and unhealthy in appearance, while in carbon dioxid they retained their color, flavor, and firmness for more than six months. He also found that berries softened much sooner in the air than in carbon dioxid. He concluded that the enzyms that participate in the changes of the carbohydrates during the ripening processes are oxidases and inhibited by carbon dioxid, an end product of oxidation.

The writers (2) have reported experiments indicating the importance of aeration and humidity in the prevention of apple-scald.

The experimental studies mentioned in the last reference (2) were continued in a much more extensive series of experiments carried out

in connection with the temperature work already reported. In the temperature experiments, as has already been mentioned, the apples were placed in moist chambers of the usual laboratory style. The tops of the containers fitted loosely, nearly always leaving cracks of 0.5 mm. or more, yet preventing a free circulation of air. The moist chambers were usually opened once a week in note taking. With all of the different experiments and at all of the different temperatures similar apples were placed in the storage boxes by the side of the moist chambers, but held in baskets or other open containers that allowed a free circulation of air. The air in the boxes was gently circulated by fans, but its rate of movement was always less than ½ mile per hour.

Gas analysis tests were made to determine the amount of carbon dioxid to which the fruit was exposed under the various conditions. The apparatus used in the determinations was that of Bonnier and Mangin (with modifications by Dr. William Crocker and George T. Harrington), and the methods, those outlined by Thoday (22). The tests showed that the free air in the 20° box had 0.42 per cent of carbon dioxid, that in the 15° box 0.30 per cent, that in the 5° box 0.24 per cent, and that in the 0° box 0.02 per cent. The larger amounts of carbon dioxid in the warmer chambers is readily accounted for by the more rapid respiration of fruit at higher temperatures and by the better aeration that would naturally be secured in the colder boxes as a result of greater contrasts between the outside and inside temperatures. It was found impossible to obtain a satisfactory sample of air from the moist chambers, as the removal of the cover from such shallow vessels allowed too free an exchange of air. At the 15° temperature it was possible to obtain samples from jars that had been handled as moist chambers, having small openings left at the stopper, and in which the percentage of scald had run parallel with that in the regular moist chambers. There was no contrast between the amount of scald on the fruit in the bottom of these jars and that on the fruit near the top. The air samples were taken from near the bottom of the jar. An analysis of these samples showed that the air contained 4.28 per cent of carbon dioxid. While complete data could not be obtained at the different temperatures, it seems evident that there was several times more carbon dioxid present in the air of the moist chambers than in the free air of the boxes.

The air in the moist chambers was kept in a saturated condition by the addition of wet filter paper, the fruit, upon removal to a warmer temperature, often being covered with a film of moisture or dotted with drops of water. The free air of the boxes was kept at a relative humidity of 85 to 95 per cent. Water always stood in the bottom of the metal boxes, but the fruit did not become perceptibly moist even upon removal for note taking; nor did it show any sign of withering even after several months of storage. In the experiments reported in figure 16, the relative humidity was lower, ranging from 55 to 70 per cent. In this

case the apples became slightly withered toward the close of the experiment.

The results obtained in the moist chambers has already been reported in figures 9 to 16, inclusive. The apples scalded badly at all temperatures when the peroid of storage was sufficiently prolonged, but the amount of the scald decreased uniformly with the temperature. In the open containers, however, the results were very different. The apples scalded upon removal from 0°, while those at all higher temperatures remained free from scald even after removal. In the case of the apples in open containers corresponding with those of the moist-chamber experiment reported in figure 16, there was a slight trace of scald in the baskets at higher temperatures, but the fact that these apples had been in cold storage six weeks before the experiment started may furnish an explanation for this. In the experiments reported in figures 10, 14, and 15, no scald occurred in the open containers at 0°, while it was found in the moist chambers at that temperature in each case. The fruit used in these tests was riper than that used in the others and the duration of the experiments was several weeks shorter. The contrasts obtained on the less mature Grimes apples are brought out in figure 17. In all cases the fruit stood in the laboratory three days before the notes were taken. It will be seen that at 0° there was but little more scald in the moist chambers than in the open containers, while at 5° the contrast was extreme, all of the apples in the moist chambers being badly scalded, while those in the open were free from scald. The contrasts at 10°, 15°, and 20° were similar to those at 5°, but appeared earlier in the experiment. It is evident that at 0° apples in open containers behaved entirely different with reference to scald from similar apples at any of the higher temperatures tested.

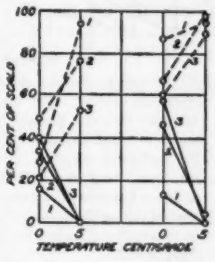

Fig. 17.—Graphs showing the amount of scald on Grimes apples from 0° and 5° C., 3 days after removal from storage. The dotted graphs show the results obtained in moist chambers, the solid graphs the results in open containers. The graphs on the left show the amount of scald on December 22, those on the right the amount on January 23. The numbers near the graphs refer to the different experiments made. 1. Experiment started on August 11, 1916. (See fig. 12.) 2. Experiment started on August 29, 1916. (See fig. 13.) 3. Experiment started on September 29, 1916. (See fig. 11.)

Careful notes were taken as to other differences between the fruit in the moist chambers and that in the open. It was found that the Grimes apples colored more rapidly in the latter case than in the former. At 15°, 20°, and 30° they reached a particular degree of color a week to 10 days earlier in the baskets than in the moist chambers, but as the lower temperatures were approached the color contrasts became less decided (fig. 18, 19, and 20). The results seem to justify the conclusion that the conditions which are favorable to the development of scald are unfavorable to the development of color in the fruit.

Other characteristics associated with ripening were also affected by the amount of ventilation. When the apples were fully ripe, those in the open were crisp, juicy, and agreeable to the taste, while those in the moist chambers, although less highly colored (in the case of Grimes) were insipid and mealy, often cracking open toward the close of the experiment. These contrasts were especially striking at the higher temperatures (including 30°). After several months of storage they became quite distinct at 5° and at the end of the experiment could usually be detected at 0°.

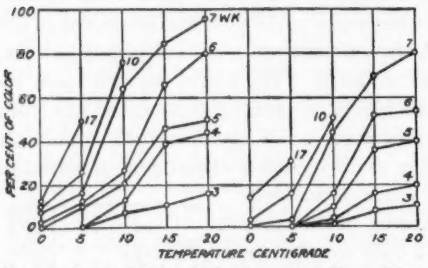

FIG. 18.—Graphs showing the development of color on Grimes apples in storage. The graphs on the left were obtained with the apples in baskets; those on the right with similar apples in moist chambers. The two series of graphs show the gradual development of the color at the different temperatures, the figures near the lines indicating the number of weeks between the starting of the experiment and the time of taking the notes. The apples were placed in storage on September 9, 1916. See figures 11 and 17 for the development of scald.

The differences in quality of the apples in the open and closed containers suggested the importance of sugar and acid determinations, but the apparatus for this work was not available till near the close of the experiment, which made it impossible to secure chemical data on the fruit that was at the higher temperatures. The determinations reported in Table II were made the latter part of January. In sampling the fruit an 18-mm. cork borer was used, the cylinders of tissue being taken parallel to the core, but not including any part of it. All of the peel was also removed from the samples. Maceration was accomplished by the use of a sampling press devised by Clark (5). The pulp was reduced to extreme fineness, which made it easy to extract the acid and sugar.

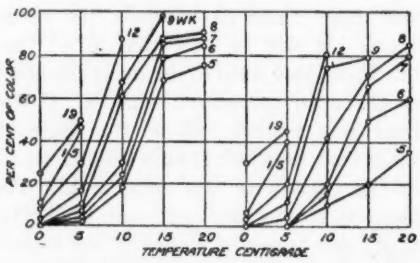

FIG. 19.—Graphs showing the development of color on Grimes apples in storage. The graphs on the left were obtained with the apples in baskets; those on the right with similar apples in moist chambers. The two series of graphs show the gradual development of the color at the different temperatures, the figures near the lines indicating the number of weeks between the starting of the experiment and the time of taking notes. The apples were placed in storage on August 29, 1916. See figures 13 and 17 for the development of scald.

In the tests on acidity distilled water was first added to the weighed pulp at the rate of 5 c. c. to each gm. of apple tissue. The diluted mixture was then heated to 100° and held at that temperature for one hour

in an Arnold sterilizer. The finely divided condition of the pulp may have made heating unnecessary for the extraction of the acid, but it was found that the hot extract could be filtered much more readily than the cold. The filtration was accomplished by means of ordinary filter paper. The pulp was allowed to drain and was then washed with distilled water until the total volume of the filtrate and washings equaled 12.5 c. c. for each gm. of original pulp. The filtrate was titrated against *N*/20 sodium hydroxid, using the color changes of the extract as an indicator described by Schley (18) and by Culpepper, Foster, and Caldwell (8). In the titrations, as well as in all the other steps of the procedure, the corresponding samples from the open and from the closed containers were carried through the tests side by side. The results of the analyses are given in Table III.

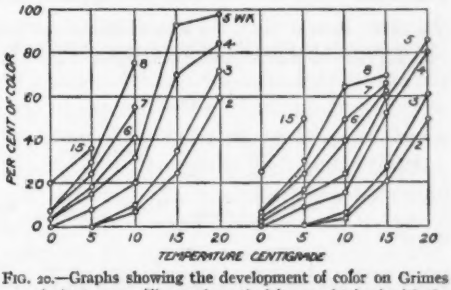

FIG. 20.—Graphs showing the development of color on Grimes apples in storage. The graphs on the left were obtained with the apples in baskets; those on the right with similar apples in moist chambers. The two series of graphs show the gradual development of color at the different temperatures, the figures near the lines indicating the number of weeks between the starting of the experiment and the time of taking notes. The apples were placed in storage on September 22, 1916. See figure 14 for the development of scald.

The method for sugar determination was essentially the same as that employed by Bryan, Given, and Straughn (4), with the exception that the extraction was made with water instead of alcohol. Earlier tests on the efficiency of the sampling press had shown that maceration was so thorough that the sugar of the pulp could be completely extracted with cold water in five minutes. The samples consisted of 20 gm. and, as already mentioned, the pulp was free from core, seeds, and peel. The proteins were precipitated with neutral lead acetate and the excess of lead precipitated with sodium oxalate. Inversion was accomplished by adding 5 c. c. of concentrated hydrochloric acid to 50 c. c. of lead-free solution and allowing it to stand overnight. The hydrochloric acid was neutralized with anhydrous sodium carbonate. The total sugars were determined by the Allihn[1] method, the cuprous oxid being determined by direct weighing. The results of the analyses are given in Table III.

In connection with the work on acids and sugars, dry-weight determinations of the pulp were also made, but only on the fruit that had been stored at 5°. In these tests the pulp was dried in an electric oven that stood at a constant temperature of 100°. The corresponding samples from the open and closed containers were always moved together, and care was taken to secure the lowest dry weight of the pulp. The

[1] WILEY, H. W., ed. OFFICIAL AND PROVISIONAL METHODS OF ANALYSIS, ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. AS COMPILED BY THE COMMITTEE ON REVISION OF METHODS. U. S. Dept. Agr. Bur. Chem. Bul. 107 (rev.), 272 p., 13 fig. 1908. Reprinted in 1912.

results showed only fractional differences between the percentage of water in the fruit from the baskets and that in the fruit from the moist chambers; the contrasts being too slight in all cases to have any important significance in the interpretation of the data on acids and sugars. The average amount of water in the skin and core-free pulp of the fruit from the open containers was 87.30 per cent, while that from the fruit in the moist chambers was 87.67 per cent. Greater contrasts might have been expected, but it should be remembered that there was only a slight contrast between the relative humidity under the two conditions of storage.

TABLE III.—*Acid and sugar in Grimes apples, determinations made on January 24–29*

[The acidity is given in numbers of cubic centimeters of *N*/20 sodium hydroxid required to neutralize the filtrate from 100 gm. of fresh pulp; the sugar as percentage of fresh pulp weight. The apples of lot 1, 2, and 3 were the same as described in the legends of figures 12, 14, and 13, respectively]

Lot No.	5° C.				0° C.			
	Acid.		Invert sugar.		Acid.		Invert sugar.	
	Basket.	Moist chamber.	Basket.	Moist chamber.	Basket.	Moist chamber.	Basket.	Moist chambe ..
1.....	111. 2	113. 5	12. 32	12. 00	100. 2	89. 3	11. 56	10. 56
2.....	89. 4	78. 0	11. 76	10. 24	.....	.....	13. 12	12. 00
3.....	106. 0	96. 2	10. 82	9. 06	118. 5	119. 9	9. 88	9. 74

The results of the acid and sugar determinations as shown in Table III bring out some interesting contrasts. There was considerable variation in the different lots of apples, but in all cases the fruit from the open containers at 5° contained more sugar and more acid than that from the moist chambers at the same temperature. At 0° similar contrasts were obtained on the sugar content from all the lots and also on the acid content of samples from lot 1, but with lot 3 the acidity was slightly greater in the fruit from the moist chambers than in that from the baskets. Tests for acidity were also made on Grimes apples from 10° with results closely parallel to those obtained at 5°.

While the results indicate that the difference in quality of the fruit that accompanied the contrasts in aeration was at least partly due to differences in the sugar and acid content of the apples, they do not seem to explain the fact that the contrast in sweetness was much greater at 5° than at 0°. Since cane sugar is several times sweeter to the taste than reducing sugars, it is possible that much of the contrast in the taste of the apples from the two conditions of storage was due to differences in the relative proportions of these sugars. Unfortunately determinations were made only of total sugar. The conversion of starch into sugar does not need to be considered in this connection, as all of the starch had disappeared from the apples much earlier in the experiment.

While the analytical data will have to be regarded as of an incomplete and preliminary nature, the results as a whole are in agreement with the observations on the taste and quality of the fruit and when considered in connection with these would seem to indicate that the conditions of storage that favor the development of scald also favor the breaking down of the acids and sugars and possibly of other complex organic compounds of the apple.

Various other experiments were made to test the effects of aeration and humidity. In one case apples were stored in a sealed jar at 15° and the air renewed three times a week. The renewal was accomplished by connecting the jar with an exhaust that under the conditions of the experiment drew out a volume of air equal to that in the jar in approximately one minute. This air exchange was allowed to continue for about 10 minutes, the stale air being withdrawn from the bottom and the fresh air being freed at the top of the jar. The incoming air was from the closed storage box and therefore of the same temperature as the air removed from the jar. It was bubbled through a wash bottle containing water and must have gone into the jar in a practically saturated condition. The walls of the jar were always covered with a film of moisture. The method of renewing the air must have left but a fraction of a percentage of carbon dioxid in the jar, but gas analysis made after the jar had stood for two days showed that the carbon dioxid had then increased to 4.49 per cent, an amount slightly greater than that already reported for jars used as moist chambers. The apples of this experiment were of the same lot as those described in the legend of figure 12. Both scald and color developed much more slowly in the above experiment than on similar apples in moist chambers at the same temperature, a particular intensity of scald appearing about four weeks later in the former case, and a particular degree of color about six weeks later. (See figures 12 and 23.) After 15 weeks of storage as above described the apples were removed to the laboratory and allowed to stand in the open for several days. There was no increase in scald, and the fruit was still firm and in fairly good condition. Some of the apples seemed to have a very faint trace of the pungent alcoholic taste described later as characteristic of apples that had received poor aeration.

A second experiment was carried out similar to the above, but the apples were of the lot described in the legend for figure 11, and the air was renewed six times a week instead of three. By reference to figure 11 it will be seen that similar apples in moist chambers at 15° had developed considerable scald at the end of four weeks and were badly scalded at the end of 5 weeks, but the apples receiving daily aeration had no scald at the end of 12 weeks and at that time had the same degree of color that those in the moist chambers had at the end of 6 weeks. (See figures 11 and 22.) There was no increase in scald when the apples were freely exposed to the air in the laboratory, and the fruit was still firm and

entirely normal in taste several weeks after it had been found necessary to discard the corresponding fruit in moist chambers.

The results of the above experiments are extremely interesting, but the data are probably insufficient for a final interpretation. The delayed development of color on the fruit in the jars as compared with that in the moist chambers should probably be attributed to a difference in aeration rather than to a difference in humidity, but this hypothesis calls for an explanation of the fact that the suppression of color was not accompanied by an increase in scald. If we should assume that scald is due to the accumulation of products of incomplete oxidation in the apple, the above condition might be explained on the ground that the frequent aerations gave opportunity for the breaking down of these organic substances without furnishing the free and continuous supply of oxygen that was necessary for the development of the skin pigment.

Other experiments were made on the effects of aeration and humidity. In one case the air of the storage jar was renewed six times a week in a manner similar to that described above, but the oxygen of the ingoing air was increased to 2 per cent above the normal amount and the air stream was continued only long enough to carry in a volume of air four times as great as the air space in the jar. In another experiment the ingoing air had 4 per cent of oxygen added, but renewal was made only three times a week. In a third case the carbon dioxid of the air was increased to 2 per cent, and renewal was made six times a week. In another experiment small openings were left at the top of the jars, and with one jar a large quantity of calcium chlorid was placed in the bottom, with another a large amount of soda-lime, while with a third neither of these absorbents was added. All of these experiments were made at a constant temperature of 15°, and the apples were of the lots described in the legends of figures 10 and 15. Under all of the different conditions described scald developed at practically the same rate, but in no case quite as rapidly as on similar fruit in moist chambers. (See figures 10 and 15.) As has already been mentioned, apples of these same lots did not scald when freely exposed in air having about 0.3 per cent carbon dioxid and a relative humidity of 85 to 95 per cent.

In an experiment at 15° with apples of the lot described in the legend to figure 11 the air was renewed three times a week, but the ingoing air had 5 per cent of carbon dioxid. The fruit remained green and did not show any sign of scald as long as it remained in the jar. Apples removed to the laboratory at the end of five weeks soon became slightly scalded, while those removed at the end of seven weeks were soon badly scalded. The fruit was found to have a pungent alcoholic flavor which it still retained after several weeks' exposure in the laboratory. It remained green, firm, and crisp under conditions that would soon have caused fresh apples to become yellow, withered, and overripe.

Apples were also stored in sealed jars at 0° and 15°. As long as the jars remained unopened little or no scald developed and the fruit remained green. When the apples were removed to the laboratory after short periods of storage, their condition was found to be similar to that described above in the experiment with 5 per cent carbon dioxid, but upon removal after longer periods of storage they had a strong odor of alcohol and vinegar, were nauseating to the taste, and soon became brown and soft, taking on the appearance of frozen apples. Gas analyses made after several weeks' storage at 15° showed that the air of the jars had more than 50 per cent of carbon dioxid.

The results indicate that storage for a short time in an atmosphere in which the carbon dioxid has been greatly increased and the oxygen correspondingly decreased causes apples to become slightly alcoholic and to take on a rigor or an inactive condition from which they do not entirely recover and that longer storage under these conditions causes the intramolecular respiration to be carried to an extent that results in the death of all the pulp cells. The fact that alcohol can be readily detected in fruit that has been stored at 15° in air having more than 5 per cent of carbon dioxid and that scald develops on fruit stored in an atmosphere having slightly less carbon dioxid might be taken as further evidence that scald is due to the accumulation of products of incomplete oxidation in the surface layers of the apple.

Further evidence on the effects of aeration and humidity were obtained with rather green Arkansas and York Imperial apples placed in commercial cold storage. In two of the barrels the apples were packed in excelsior, while in the others they were packed in the usual manner. The apples were removed from cold storage on February 24, and after three days in the laboratory it was found that the former lot had about 10 per cent of scald, while the latter had 65 per cent.

Scald is sometimes of a somewhat local nature, and it can be produced on one part of an apple without the other parts showing any abnormal effects. In an experiment on aeration and humidity a small amount of water was placed in each of several tumblers and then an apple dropped into the top of each. The lines of contact between the apples and tumblers were sealed with a wax compound of beeswax, vaseline, and tallow. The lower halves of the apples were thus under moist-chamber conditions, while the upper halves were well aerated. The inclosed halves soon developed scald, while the exposed parts remained free from it (Pl. 33, C). It has been repeatedly observed that apples which were standing in films of water became scalded at the point of contact, while the rest of the skin remained normal. It has also been noticed that in the first stages of scald the brown discoloration sometimes appears in small spots instead of being evenly distributed over the skin. This was especially true where the conditions had been such as to condense the mois-

ture in drops over the surface of the apple. It is the opinion of the writers that this uneven distribution of the moisture was at least partly responsible for the spotted condition of the fruit. Experiments were made in covering portions of the apple with vaseline and exposing the fruit to conditions favorable for the development of scald. No evidence was found of any relationship between the distribution of the vaseline and the occurrence of scald.

RELATION OF THE MATURITY OF FRUIT ON APPLE-SCALD

It has frequently been reported that green fruit scalds worse than ripe fruit. The writers' observations are in general agreement with this statement. They have not found, however, that green fruit scalds quicker than ripe fruit, but rather that the opposite condition often holds.

The results of an experiment on the effects of early and late picking may be seen by a comparison of the curves in figures 12, 13, and 14. All of the apples were from the same Grimes tree, but those of figure 12 were picked on August 10, those of figure 13, on August 28, and those of figure 14 on September 21. By comparing the corresponding curves in the different figures it will be seen that up to the end of the seventh or eighth week the ripe apples were in most cases scalding more rapidly than the green ones. This condition held in spite of the fact that the apples of figure 12 were picked in much warmer weather than the others, a circumstance that might be considered favorable to the development of scald.

In taking notes on the various experiments already reported observations were also made on the comparative susceptibility of the greenest and ripest fruit of a particular picking. With the earlier pickings it was found that the ripest apples nearly always scalded first and that the blush side of the fruit usually scalded before the other. With the later pickings this condition did not hold and in some cases scald was confined almost entirely to the greener fruit surfaces.

Similar results were obtained on rather green Arkansas and York Imperial apples in commerical cold storage. The apples were picked on October 17, 1915, at Middletown, Va., and were placed in cold storage three days later. They were removed from storage on February 23. It was found that apples that were red on one side and a yellowish green on the other were usually scalded only on the greener side, but that apples that were a yellowish green or a streaked yellow on one side and a bright green on the other were scalded most on the riper side.

The results indicate that while the statement that green fruit is more susceptible to scald than ripe fruit holds with usual commercial practice, it does not hold for all degrees of maturity; nor does it follow that green fruit will scald more quickly than ripe. The data suggest a very close

relationship between a particular degree of maturity and the development of scald.

In order to obtain further information on the relation of maturity of fruit to susceptibility to scald, careful notes were taken in the various experiments already reported on the development of the skin color in the apple. The degree of color was determined in a manner similar to that already given for the estimation of the amount of scald, the intensity of the color being compared with the maximum color that the fruit was likely to acquire. Records were always made by two observers and notes were taken without reference to earlier records.

The results given in figures 18, 19, and 20, were from the same lots of apples, respectively, as the scald notes of figures 11, 13, and 14. Temperature is indicated on the base line and percentage of color on the perpendicular. The conditions of the experiments have already been described; the apples in the open containers were exposed in an atmosphere that had less than 0.05 per cent of carbon dioxid and that had a relative humidity of 85 to 95 per cent, while those in the moist chambers were subjected to an atmosphere that was practically saturated and that sometimes had as much as 4 per cent of carbon dioxid.

It is interesting to note that the color changes were made more rapidly during certain periods of storage than in others and that there was often a correlation between the time of greatest color change and that of greatest scald development. If figures 11 and 18 are compared, it will be seen that at 15° and 20° there was a decided increase in color in the open containers in the fourth week and in the moist chambers in the fifth week and that at these temperatures scald made its most rapid development in the fifth week. At 10° the most rapid color changes came in the seventh week while the most rapid scald development came in the ninth week. A comparison of figures 13 and 19 brings out similar conditions. At 15° and 20° there was a big increase in color in the moist chambers during the sixth week and a big increase in scald during the seventh week. At 10° there was a big increase in color in the eighth week and a big increase in scald in the ninth week. In general the period of most rapid scald development has come about one week later at these higher temperatures than the time of most rapid color change. This correlation gives further evidence of the close relationship between the chemical changes in the apple and the development of scald.

A comparison of the results obtained in moist chambers with those in the open containers (as given in fig. 18, 19, and 20) shows that in the early stages of the experiment a particular degree of color was attained one or two weeks earlier in the latter case than in the former. The results indicate that the conditions that have already been reported as favoring scald have also tended to check the development of the skin color in the apple.

In the interpretation of the above contrasts in color development it becomes of interest to know whether the depressing effect of the moist chambers was due to the high humidity or the poor aeration. Some further experiments carried out at 15° throw light upon this subject. As has already been stated, two boxes were maintained at this temperature, one in which the relative humidity ranged from 65 to 75 per cent but usually stood at 70 per cent, and another in which the relative humidity ranged from 85 to 95 per cent and usually stood slightly above 90 per cent. There was less fruit in the former box and the accumulation of carbon dioxid may therefore have been slightly less in this case than in the more humid box. In figures 21, 22, and 23 the color development in the open containers under these conditions is compared with that in moist chambers at the same temperature. In figures 22 and 23 other curves are given showing the color development on apples in jars where the air was kept saturated, but was renewed several times a week.

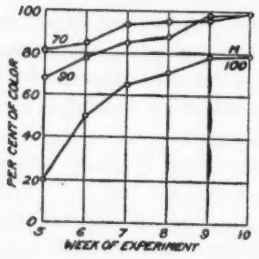

FIG. 21.—Graphs showing the influence of aeration and humidity upon the color development of Grimes apples in storage at 15° C. The perpendicular indicates the percentage of color, the base line the number of weeks of storage, and the curves give the comparative color development obtained with 70, 90, and 100 per cent relative humidity, respectively. With the graph marked "M100" the apples were held in moist chambers, while with the others they were kept in open containers. The apples were of the same lot as described in the legend of figure 13.

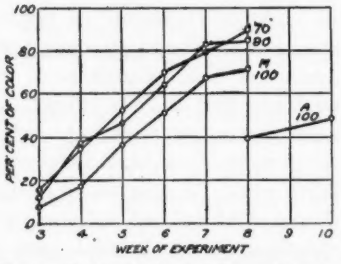

FIG. 22.—Graphs showing the influence of aeration and humidity upon the color development of Grimes apples in storage at 15° C. The perpendicular indicates the percentage of color, the base line the number of weeks of storage, and the curves give the comparative color development with 70, 90, and 100 per cent relative humidity, respectively. With the graph marked "M100" the apples were held in moist chambers, with the one marked "A100" they were in closed jars that had the air renewed six times a week, and in the other two cases they were kept in open containers. The apples were of the same lot as described in the legend of figure 11.

There was practically no contrast in color development between well-aerated apples exposed to a relative humidity of 70 per cent and similar apples exposed to a relative humidity of 90 per cent. It has already been pointed out that apples did not scald under either of these conditions. The color development in the moist chambers was much slower than in either of the above cases. The relative humidity was 10 per cent higher in this case than in either of the former, and, as pointed out earlier in the paper, the aeration was very poor. Since increasing the relative humidity from 70 to 90 per cent has caused no checking in color development, it does not seem probable that increasing it from 90 to 100 per cent would do so. In so far as this reasoning can be

relied upon, evidence is furnished that the checking of color development in the moist chambers was due to poor aeration and not to high humidity. The contrast between the color development in the moist chambers and that in the sealed jars where the air was renewed but a few times a week was very striking. The air was apparently saturated in both cases, leaving no chance to attribute the contrast to a difference in humidity; but the carbon dioxid, although more intermittent, reached higher percentages in the latter case than in the former. The delayed color development in the latter case must therefore be attributed to poor aeration rather than to any difference in humidity.[1]

EFFECT OF DELAYED STORAGE ON APPLE-SCALD

Powell and Fulton (17) and Markell (14) have reported that a delay in storage is favorable to the development of apple-scald. Green (11) recently found that Grimes and Sheriff apples that were stored immediately after picking developed more scald than those that were held at a warmer temperature a few weeks before placing in storage. He attributed the difference to the fact that the fruit that was left out of storage for a time had opportunity to become more mature and therefore less susceptible to scald.

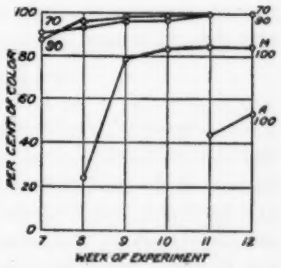

FIG. 23.—Graphs showing the influence of aeration and humidity upon the color development of Grimes apples in storage at 15° C. The perpendicular indicates the percentage of color, the base line the number of weeks of storage, and the curves give the comparative color development with 70, 90, and 100 per cent relative humidity, respectively. With the graph marked "M100" the apples were held in moist chambers, with the one marked "A100" they were in closed jars that had the air renewed six times a week and in the other two cases they were kept in open containers. The apples were of the same lot as described in the legend of figure 12.

The writers have obtained results similar to those of Green. Ten barrels of Grimes apples were picked at Middletown, Va., on September 7. Five barrels were shipped by express and were placed in cold storage on September 9, while the other five were shipped by freight and were stored on September 14. All of the apples were removed on December 19. After standing for three days at laboratory temperature, it was found that the scald on the apples that were delayed in reaching storage averaged 20 per cent, while that on the apples stored five days earlier was 54 per cent. The former lot of apples was found to have become decidedly riper than the latter, and it seems probable that the

[1] Since writing the above, the attention of the writers has been called to the recent work of Shamel (20) in which he reports that Bartlett pears were held for 30 days at an average temperature of 90° F. (32⅔° C.) in an atmosphere having a relative humidity of approximately 90 per cent without any apparent change in the fruit and in which he expresses the belief that the ripening of the pears was prevented by the excessive humidity of the storage room. The room was partly filled with lemons undergoing the curing process and was ventilated for half an hour daily for a number of days about the end of the second week. The author does not discuss the significance of the ventilation; nor does he give any data as to the accumulation of carbon dioxid during the periods when the room was not ventilated.

explanation of the contrast in scald is to be found in this difference in maturity of fruit.

The results of the above experiment might seem to be in opposition to the generally accepted idea that immediate storage tends to decrease scald, but it is evident from the experiments (reported earlier in this paper) that the effects of delayed storage will depend upon the conditions under which the apples are held during the delay, and possibly also upon the initial maturity of the fruit.

It has already been pointed out that when fruit is poorly aerated scald increases with an increase in temperature up to 15° or 20°, and that when it is well aerated it will remain free from scald at any temperature from 5° to 20°. The effect upon scald development of any delay in reaching storage should therefore depend very largely upon the aeration and humidity during the prestorage period. If the aeration is sufficient, there will not only be no scald tendencies developed at the warmer temperatures, but the fruit will mature rapidly during the delay and thus, in general, become less susceptible to scald.

DISCUSSION OF RESULTS

The results of the various experiments point to abnormal respiratory conditions as the cause of scald. The disease has been readily produced by storing the fruit in moist chambers, in loosely stoppered jars, or under any condition that furnished a slight restriction to aeration. Scald has not developed on well-aerated apples (at temperatures above 0°); nor has it been found possible to produce typical scald in tightly-sealed containers.

No evidence has been obtained that humidity has any effect upon the development of scald except under conditions that have caused the deposition of drops or films of water on the skin of the apple. In such cases it seems probable that the harmful effects were due primarily to the partial exclusion of the air or to the retention of oxidation products by the water.

The rapidity of the development of scald has increased with an increase in temperature. In this fact it has followed the law of respiratory activities. Morse (15) found that between 0° and 20° a rise of 10 degrees in temperature caused a doubling of the amount of carbon dioxid given off by Baldwin apples. Gore (10) reported that in determinations including 40 different kinds of fruits it was found that respiration increased from 1.89 to 3.01 times, an average of 2.376 times for each 10-degree rise in temperature. A study of figures 10 to 17 shows that the average rate at which the development of scald has increased with a rise in temperature is approximately the same as the rate of increase for respiration. The question might be raised whether the more rapid development of scald at the higher temperatures might not be entirely due to the greater

accumulation of carbon dioxid, but this does not seem probable. The tops of the moist chambers fitted loosely, and any increased accumulation in carbon dioxid would undoubtedly have been largely balanced by an increased air exchange. It is also probable that a higher percentage of carbon dioxid would be required to give a particular degree of inhibition at a high temperature than at a low one. Kidd (13) found that a rise of 10 degrees in temperature necessitated, roughly, the presence of three times as high a partial pressure of carbon dioxid to cause an inhibition of germination in the seeds of *Brassica alba*. It seems probable that the more rapid development of apple-scald at the higher temperatures should be attributed to the more rapid procedure of respiratory activities that have become abnormal rather than to any greater inhibitory action of the accumulated carbon dioxid.

Scald has not occurred at 30° either in moist chambers or in open containers. This may have been due to the fact that the carbon dioxid oxygen ratio did not become high enough to cause a sufficiently disturbing effect upon respiratory activities at such a high temperature. The skin color changes, however, were peculiar at this temperature, indicating the possibility of other causes for the absence of scald.

Scald occurred at 0° in the open containers, but not at 5° or at any of the higher temperatures. This contrast might be attributed to the greater inhibiting value of carbon dioxid at low temperatures, but the relatively small amount of this gas found in the 0° box has not furnished any support for this theory. It is the opinion of the writers that the development of scald at 0° under conditions that have not produced it at higher temperatures should be at least partly credited to the depressing effect of the low temperature itself. It is especially interesting in this connection to note that scald has not become evident while the apples were at 0°, even when it has been actually produced at that temperature. The skin sometimes took a slightly faded watery appearance, but it did not turn brown till the apples had been removed to a warmer temperature. The inhibition of the browning at 0° should probably be attributed to the suppressing effect of the low temperature upon the oxidizing enzyms of the apple skin, and it would certainly not be surprising if a temperature that has inhibited oxidation color changes should also have its peculiar effects upon the oxidation connected with respiration.

Scald apparently results from some effect that acts as a cumulative agent. Its rate of development is influenced by temperature, by the maturity of the fruit, and within certain limits by the degree of aeration, but it has not been found possible to produce it in a short period of time by the intensification of any favoring agency.

Apples stored under conditions favorable to the development of scald but removed to other conditions before a certain critical period is reached apparently do not retain their accumulated scald tendencies. A striking

example of this is seen in the curves of the Grimes apples of figures 11 and 15. Both were of the same lot, but those of the latter figure had been in commercial cold storage five weeks before the particular experiment was started. These apples had a day's aeration in the laboratory and were then divided up and placed at the various temperatures of the experiment. Those in moist chambers at 0° scalded as quickly as those left in commercial cold storage or as those of figure 12 that were placed at 0° in the beginning, but those in moist chambers at 10°, 15°, and 20° scalded far more slowly than similar apples that had never been in storage. (See figures 11 and 15.) The cold-storage apples placed in open containers did not scald at any of the temperatures, while the apples from cold storage did not scald at 0° in open containers; those placed under this condition at first had 60 per cent of scald by the end of the experiment. (See curve 3, figure 17.) The checking effects of cold storage must not be overlooked, but the fact remains that apples stored at 0° for more than one-third of the time necessary to produce scald at that temperature have scalded much more slowly upon removal to other conditions than similar apples fresh from the tree.

Scald may be local in its effects; one side of the apple may be scalded and the other not; or scald spots may be scattered over the surface of the apple.

The production of apple-scald has been accompanied by a reduction in the sugar and acid content of the apple, by a retardation in skin color changes (in Grimes) and by an increase in mealiness, all of which might be considered as the expected result of respiration carried out under conditions of restricted aeration. When the aeration has been further decreased, scald has not occurred; but alcohol and various nauseating odors have been produced, suggesting a high degree of intramolecular respiration. The results seem to indicate that apple-scald is produced by the long-continued action of slightly abnormal respiratory conditions.

Much that has been said in regard to the nature of scald has been found true of Jonathan-spot. The two diseases are alike in the tissue affected; they have similar temperature responses and are similarly affected by aeration and humidity and by maturity of fruit. In all these cases the response has been much less striking with Jonathan-spot than with apple-scald, but the similarities are great enough to suggest some close relationship in the fundamental causes of the two diseases.

SUMMARY

(1) Jonathan-spot and apple-scald have shown many similarities. The initial stages of both diseases were found to be confined to the color-bearing cells of the skin. Both rendered the apples susceptible to rot infections. Both were decreased by good aeration and by a fair degree

of maturity in the fruit, and both increased with a rise in temperature, having an optimum at about 20° and a maximum at about 30° C.

(2) On Grimes and York Imperial apples scald developed in moist chambers at 0°, 5°, 10°, 15°, and 20° C., the rapidity of development increasing with the rise in temperature. In open containers, however, no scald developed at any of the above temperatures except 0°. Grimes apples in closed jars but with the air renewed once a day have scalded much more slowly than similar apples in moist chambers.

(3) Apples stored at 15° C. in an atmosphere having a high percentage of carbon dioxid (probably more than 5 per cent in all cases) have not developed typical scald, but have first passed into a sort of rigor, have later developed a pungent alcoholic taste, and have finally broken down throughout like a baked or frozen apple.

(4) The writers are of the opinion that apple-scald is largely due to abnormal respiratory conditions resulting from poor aeration. It has been pointed out that the occurrence of scald has been accompanied by a decrease in total acids and sugars, by a mealiness in the flesh of the apple, and by a checking in the color changes in the skin (Grimes). In looking for the final cause of scald, one should consider both the abnormal consumption of the organic food materials and the accumulation of the products of incomplete oxidation.

(5) The conditions within the apple tissue which finally result in scald are of a cumulative nature and apples removed from unfavorable storage conditions before a certain critical period was reached have shown little or no increased susceptibility to the disease.

(6) The rate of skin color development in Grimes apples has increased with a rise in temperature from 0° to 30° C. It has been checked by poor aeration, but apparently has been little affected by the degree of humidity.

(7) Apple-scald has been found more serious on green fruit than on ripe fruit, but it has developed more rapidly on the latter.

(8) Apples that have been delayed in storage have developed less scald than those stored immediately, but results of other experiments reported make it evident that the effect of delayed storage upon apple-scald will depend upon the initial maturity of the fruit and the degree of aeration given during the delay.

(9) Grimes apples held in commercial cold storage for five weeks, about one-third the time required to produce scald under cold-storage conditions, have shown much less susceptibility to the disease upon removal to other conditions than apples of the same picking tested five weeks earlier.

(10) The important rôle that aeration appears to play in the prevention of apple-scald may furnish an explanation for the small amount of this disease usually found in cellar and air-cooled storage.

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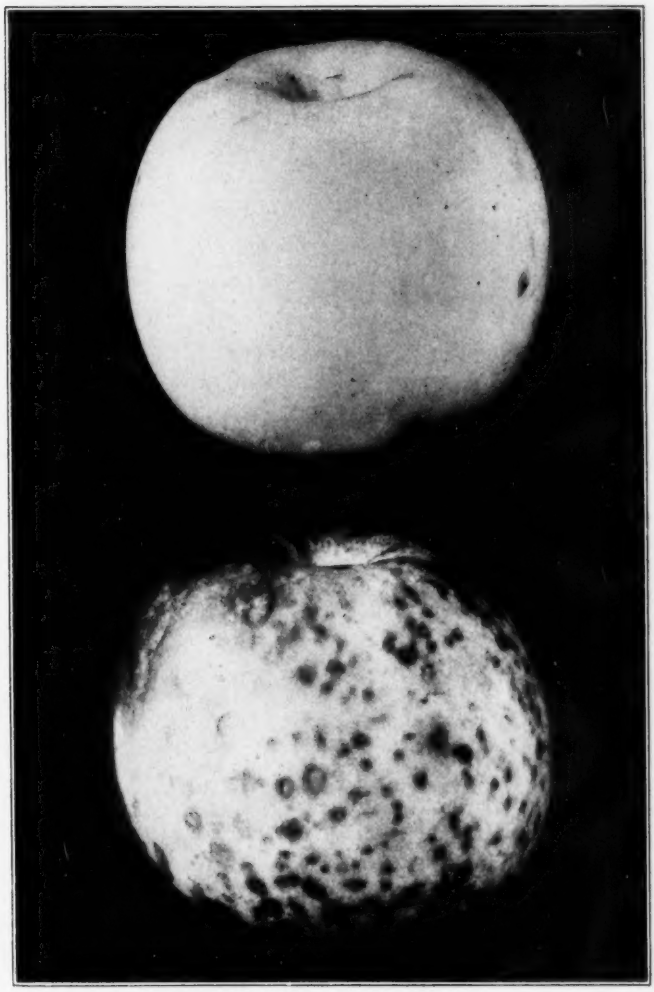
PLATE 32

Apple-scald:

Grimes apples showing the effect of storing at 15° C. from September 9 to October 30. The upper apple was stored in an open container and remained free from scald. The lower apple was stored in a moist chamber and became scalded.



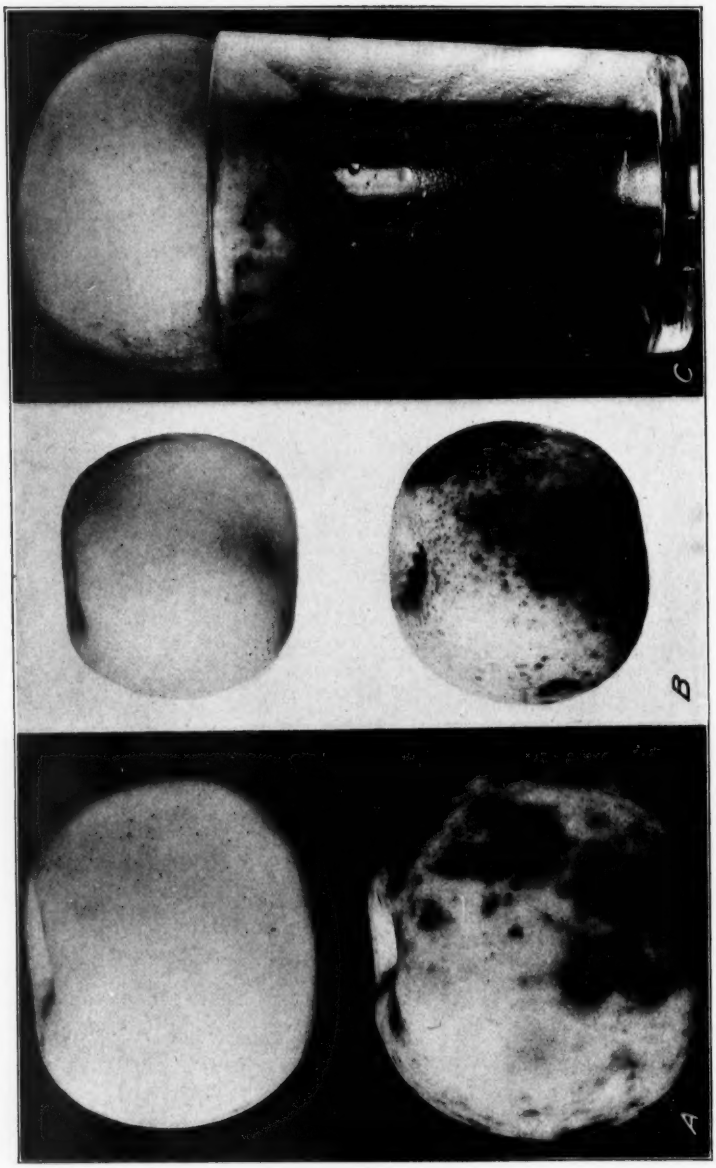

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PLATE 33

Apple-scald:

A.—Grimes apples, showing the effect of storing at 10° C. from September 9 to November 20. The upper apple was stored in an open container and remained free from scald. The lower apple was stored in a moist chamber and was badly scalded at the end of the period.

B.—Grimes apples, showing the effect of storing them at 10° C. from August 11 to October 17. The upper apple was stored in an open container and remained free from scald. The lower apple was stored in a moist chamber and became scalded.

C.—An apple with part of its surface inclosed in a tumbler. The inclosed portion shows an early stage of scald, while the part that is outside is free from scald.

STUDIES IN GREENHOUSE FUMIGATION WITH HYDROCYANIC ACID: PHYSIOLOGICAL EFFECTS ON THE PLANT [1]

By WILLIAM MOORE, *Head of Section of Research in Economic Zoology, and* J. J. WILLAMAN, *Assistant Chemist, Minnesota Agricultural Experiment Station*

INTRODUCTION

In a previous paper (15)[2] the relationship between temperature and moisture to the degree of injury to plants fumigated with hydrocyanic acid was considered. The next step in the investigation has been to determine the action of the gas on the tissues of the plant. Little information on this point is to be found in the literature. In fact, some investigators have considered the injury to be not due to hydrocyanic acid, but to hydrochloric-acid fumes generated from sodium-chlorid impurities in the commercial cyanid (24). The reactions of hydrocyanic acid on isolated compounds have received considerable attention, but not from the standpoint of injury to plants during fumigation. The object of this paper is to show that hydrocyanic acid penetrates the tissues and is responsible for certain disturbances in the metabolism of the plant which may result in injury or even death.

EVIDENCE OF THE PENETRATION OF THE GAS

In order to demonstrate the actual presence of the hydrocyanic acid in the plant, chemical analyses were made at various intervals after fumigation.

From 60 to 130 gm. of tomato plants, usually 8 to 20 plants, were ground in a food chopper, suspended in a Kjeldahl flask in 300 c. c. of 5 per cent tartaric acid, and slowly distilled into a little 5 per cent sodium hydroxid until 100 c. c. of distillate were obtained. The cyanid in this distillate was then estimated by the method of Viehoever and Johns (22). A portion of the sample of tissue was used for the determination of dry matter.

The results are given in Table I. It is evident that there is an appreciable amount of cyanid absorbed, and that this amount is proportional to the injury produced. These figures are only comparative, since it is impossible to recover quantitatively the hydrocyanic acid contained in a plant tissue (1, 23). The acid disappears within a few hours after fumigation; and it is during this period, as will be shown later, that certain physiological disturbances are evident.

[1] Published, with the approval of the Director, as Paper No. 69 of the Journal Series of the Minnesota Experiment Station.

[2] Reference is made by number to "Literature cited," p. 336-338.

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TABLE I.—*Amounts of hydrocyanic acid absorbed by the plants during fumigation*

[Results expressed as percentage of hydrocyanic acid in dry weight of plants]

Set No.	Time after fumigation.	Percentage of hydrocyanic acid to dry matter.	Injury to plants.	Dose.
	Hours.			
Set I	0.0	0.0037	Slight burning	1 gm. of potassium cyanid per cubic meter for 1 hour
Set II	.0	.0047	Severly injured	Do.
	.6	.0041	do	Do.
	1.2	.0037	do	Do.
	2.0	.0027	do	Do.
Set III	.0	.0100	do	1 gm. of potassium cyanid per cubic meter for 1.5 hours.
	1.5	.0077	do	Do.
	5.6	.0032	do	Do.
Set IV	.0	.0006	Not injured	1 gm. of potassium cyanid per cubic meter for 1 hour.
	1.5	.0000	do	Do.
Set V	.0	.0090	Severely injured	1.25 gm. of potassium cyanid per cubic meter for 1 hour.
	2.0	.0060	do	Do.

In the work reported in the previous paper (15) there was evidence that the absorbed hydrocyanic acid was given off from the leaves into the atmosphere after removal from the fumigation chamber, since plants were least injured when put under conditions favorable to rapid evaporation of the hydrogen cyanid. That the acid, however, may be partly or completely destroyed in the tissues is suggested by the work of Schmidt (18) and of Dezani (7), in which there was reported the destruction of a considerable portion of the absorbed or injected cyanid, by the sap of fruit, stem, and leaves. To determine, if possible, the fate in tomato plants of hydrocyanic acid absorbed during fumigation, resort was had to Mirande's (13) sodium-picrate test paper for the detection of the acid given off by leaves. After fumigation one plant was placed in a bell jar just large enough to contain it, with a strip of the moist test paper suspended among the leaves from the top of the jar. The leaves from another plant were packed loosely in a jar with strips of test paper. After two hours a slight orange tinge was observed on the latter paper, but none on the paper under the bell jar. The color represented an amount of evolved cyanid gas equal to only an extremely small fraction of the amount that must have been contained in the leaves. It seems, therefore, that most of the hydrocyanic acid is destroyed by the tissues, being either united with sugars or converted into ammonia. It is rather probable that the hydrocyanic acid which actually gains entrance to the cells is never evolved from them again and that the acid which is still within the intercellular spaces and in the cuticle at the close of the fumigation may be evaporated into the atmosphere if placed under the proper conditions.

EFFECT OF THE ENZYMIC ACTIVITIES OF THE PLANTS

Geppert's (10) work has proved conclusively that in the higher animals absorbed hydrocyanic acid limits oxygen transfer in the tissues. Loevenhart and Kastle (12) have shown that the gas is able to paralyze the catalytic activity of solutions of metallic colloids. Kastle and Loevenhart (11) showed that hydrogen cyanid inhibits the action of potato oxidases, while recently Shafer (19) has shown that it affects the activities of oxidases, catalase, and reductase in insect tissues. One would expect, therefore, to find that in plants which had absorbed hydrocyanic acid during fumigation the respiratory enzyms at least were affected. Enzyms other than those connected with respiration were tested for the effect of hydrocyanic acid as follows: Commercial pepsin acting on coagulated white of egg; proteases extracted from tomato leaves acting on coagulated fibrin; taka diastase and diastase from tomato leaves acting on soluble starch; zymase acting on dextrose; rennin. The result in each case was that there was no apparent effect on these enzyms, either in speed of action or in total change produced.

Among the respiratory enzyms studied were oxidases, catalase, and reductase. In this paper these terms should be construed as follows: Oxidases are the substances which will cause transfer of atmospheric oxygen to aromatic chromogens, such as hydroquinone, pyrogallol, and the cresols. Catalase liberates molecular oxygen from hydrogen peroxid. The reductase activity sought here was the decolorizing of methylene blue in the absence of oxygen. Two kinds of preparations for enzym work were used: First, the juice of the leaves, obtained by grinding them in a food chopper and squeezing through silk bolting cloth; second, the dried leaf powder, obtained by drying the leaves in a vacuum desiccator over quicklime, then powdering in a mortar and sifting through No. 12 bolting cloth.

OXIDASES.—For the quantitative determination of oxidase activity Bunzel's (6) simpler apparatus was employed. A temperature of 37° C. was used in all determinations; 0.1 gm. of leaf powder was allowed to act on 0.01 gm. of oxidizable chemical until the reading was constant, usually 1.5 to 2.0 hours. As a preliminary a number of oxidizable chemicals were tried. Since pyrocatechol and hydroquinone gave the best results, they were used in this work.

In order to demonstrate that the presence of hydrocyanic acid inhibits oxidase activity, powder from normal tomato leaves was placed in one arm of the Bunzel tubes and varying concentrations of hydrogen cyanid, together with hydroquinone, were placed in the other arm. In this way the cyanid and the leaf powder did not come in contact except during the reaction period. The results are shown in figure 1. It is evident that there is a rapid decline in activity in the presence of even very small amounts of the poison.

Next, in order to show whether the hydrocyanic acid destroys or combines with the enzym and exerts its effect even after the poison has been removed and when it is not present during the oxidase reaction, the following experiments were performed: 0.4 gm. of leaf powder on a watch glass was made into a paste with 1.0 c. c. of the hydrocyanic-acid solution to be tested, covered with another watch glass and allowed to stand for varying lengths of time; then placed in a vacuum desiccator for 24 hours. After powdering it in a mortar it was sieved through No. 12 silk bolting cloth and used for oxidase determination, as in the original powder. The results are shown in figure 2. The curves indicate that there is no permanent injury to the oxidase activity of these powders following treatment with hydrocyanic acid, and that if there is any change at all it is a slightly increased activity.

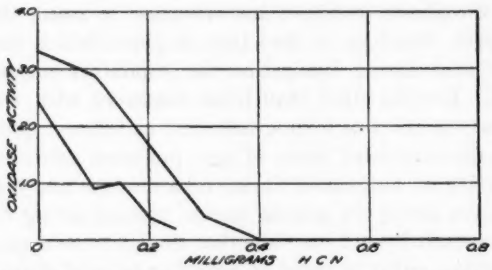

FIG. 1.—Curves showing in two samples of tomato leaves the effect on oxidase activity of the presence of hydrocyanic acid during the determination.

To show the effect of fumigation with hydrocyanic acid on the oxidases of tomato plants (*Lycopersicon esculentum*), a group of plants about 30 cm. high was divided into two sets. One set was fumigated with 1.0 gm. of potassium cyanid per cubic meter for one hour in the middle of the day; the other group was held as normal. At stated intervals before and after fumigation samples consisting of the upper three leaves of the plants (since the younger leaves always show effects of fumigations more

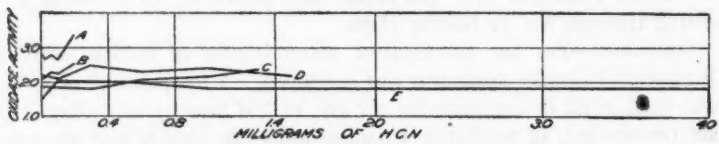

FIG. 2.—Curves showing the oxidase activity of leaf powders treated with varying concentrations of hydrocyanic-acid solution, the latter having been removed before the determination was made: *A*, treated 15 minutes before desiccation; *B*, *C*, *D*, *E*, treated 2 hours before desiccation.

and contain the more active oxidases) were taken and prepared in the powder form for analysis. The data are shown in the upper curves of figure 3. There is a sudden and striking drop in oxidase activity exhibited by the fumigated group at the close of the fumigation. This is followed by a rapid recovery to normal within 13 hours. The experiment was repeated with a second group of plants with similar results, as shown in the lower curves of figure 3. In this case the recovery was even more rapid, being complete in two hours.

The permanency of this recovery is shown by the following experiments. A uniform group of tomato plants about 17 cm. high was divided into four sets of 30 plants each. No. 6 was normal, unfumigated. No. 7 was fumigated from 7.20 to 8.50 p. m. with 1 gm. of potassium cyanid per cubic meter of air at a temperature of 13° C. Owing to the low temperature half the plants were killed, and experimental work could not be started on the other half until four weeks later. No. 8 was fumigated with 0.25 gm. of potassium cyanid per cubic meter overnight 3 times at

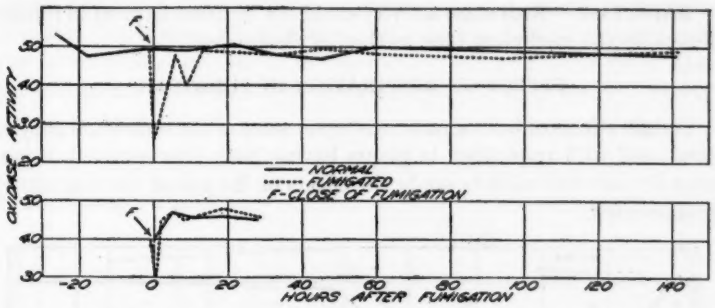

FIG. 3.—Curves showing the hourly activity of the oxidases of fumigated and of normal tomato plants.

2-week intervals. There was no visible injury. No. 9 was fumigated with 0.25 gm. of potassium cyanid per cubic meter overnight 10 times at 3-day intervals. Samples for oxidase analysis were taken at intervals and prepared in the powder form. Figure 4 gives the results. The curves indicate that there is in general no permanent decrease in oxidase activity except in the group very frequently fumigated.

Many other determinations on the fresh juice of tomatoes, working with both hydroquinone and pyrocatechol, confirmed the above results.

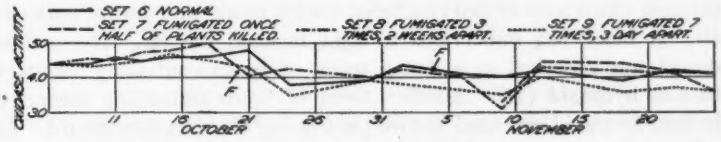

FIG. 4.—Curves showing the oxidase activity of fumigated and of unfumigated tomato plants over a period of eight weeks. *F*, close of fumigation.

CATALASE.—For the quantitative determination of catalase activity 0.025 gm. of the powder, or 0.13 c. c. of juice, was allowed to act on 2.0 c. c. of 3 per cent hydrogen peroxid in Bunzel tubes graduated to read positive pressures (2). A temperature of 37° C. was always used, and the reaction allowed to continue for 15 minutes. According to Appleman, catalases are rapidly destroyed by contact with acid plant juices, and calcium carbonate has to be added as a preventive. This was not found to be the case with tomato juices, however, and calcium carbonate was not used in these determinations.

The data in figure 5 show that with catalase, as well as with the oxidases, there is a temporary decrease activity at the close of fumigation, followed by a rapid recovery. The catalase differs from the oxidase activity, however, in that it not only recovers to the normal but that it actually exceeds the normal in considerable degree. The increase above normal at the end of the series of samples is much more marked than the decrease below normal at the beginning, which is the reverse of that found in the oxidase curves.

REDUCTASE.—Reductase activity could not be demonstrated in tomato leaves by the methylene-blue method of Shafer (19).

EFFECT ON RESPIRATION IN TOMATOES

Certain effects of hydrocyanic acid upon some of the individual enzyms connected with respiration in plants having been demonstrated, it was next deemed advisable to study the effects of the gas on the respiratory process itself.

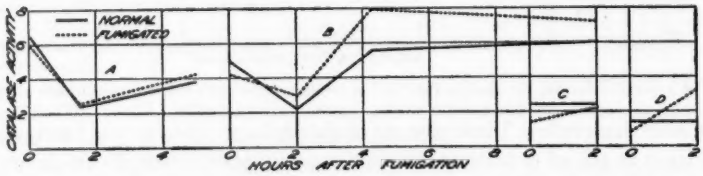

FIG. 5.—Curves showing the effect of hydrocyanic-acid fumigation on the activity of the catalase in tomato. *A* and *B*, juice used; *C* and *D*, leaf powder used.

The amount of carbon dioxid given off by a plant in the dark during a specified period was used as the index of comparative respiration between fumigated and unfumigated plants. The respiration chamber was a glass jar 30 cm. high and 13 cm. in diameter, fitted with a ground-glass stopper, through which were drilled two holes, one for intake and one for outlet of air. A black bag impervious to light inclosed the jar. The carbon dioxid was absorbed in a Truog tower of beads containing standard barium hydroxid (21). Another tower of beads containing saturated barium hydroxid was used to free the ingoing air of carbon dioxid. In order to avoid laboratory air, a long tube connected the apparatus with the outdoor air through a window. By means of a water pump air was aspirated vigorously through the apparatus for 40 minutes. It was found by testing against pure calcite that this length of time for this sized chamber always gave 95 to 98 per cent recovery of the contained carbon dioxid, which was sufficiently accurate for the comparative purposes at hand. Two jars and two plants, one normal and the other fumigated, were always run side by side, and all conditions were as nearly identical as possible. The temperature varied from 20° to 25° C. Five or six potted tomato plants from 15 to 20 cm. high were put in the dark for an hour. Three of them were then fumigated in the dark, the others

meanwhile being kept in the dark. At the close of the fumigation one normal and one fumigated plant were selected for respiration measurements, the others being returned to the greenhouse to observe the extent of injury. The pots and soil surface of the two experimental plants were thoroughly paraffined to avoid the evolution of carbon dioxid. The plants were put into their respective jars, the latter sealed tight with paraffin, and the air freed from carbon dioxid. For the first day or two the respired carbon dioxid was measured every three to six hours, as is shown in figure 6. Since the atmosphere in the jars quickly became saturated with moisture, transpiration nearly ceased; hence the plants were not under normal conditions in this respect, and as a result there was a general decline in respiratory activity during the first 30 hours. As both

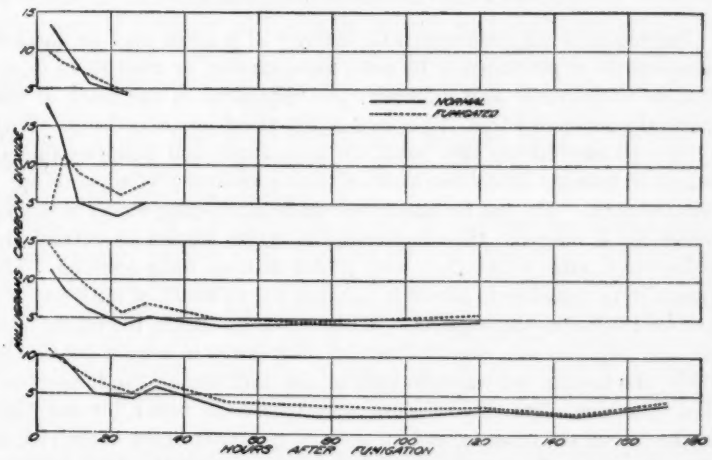

FIG. 6.—Curves showing the rate of respiration (in milligrams of carbon dioxid per hour per 1 gm. of dry matter in plant) of four pairs of tomato plants. From top to bottom the groups are arranged in order of increasing injury from hydrocyanic-acid fumigation.

plants, however, were under the same conditions throughout, it was not deemed necessary to install a drying medium in the jars. At the end of the experiment the plants were removed and the dry weight of each determined, to form a basis for calculation. Although in all four of the experiments carried out the fumigation dose was the same, there was considerable difference in the gross effect on the plants, owing to other varying factors (15). The first showed no apparent injury; in the second the leaves curled, but did not wilt; in the last two the smaller leaves and stems wilted, and some did not recover. This selective injury produced different types of respiration curves.

As is shown in the two upper curves, a slight injury results in a material decrease in the amount of respired carbon dioxid at the end of the fumigation. This is followed by a rapid recovery not only to normal, but in

excess of the normal. With greater injury (the two lower curves), however, the respiration is above normal even at the close of the fumigation. It remained above normal throughout the experiments, periods of five to seven days. A normal fumigation with hydrocyanic acid therefore results in a temporary decrease, followed by an increase in respiration. It is interesting to note at this point the correlation in the form of the curves of the catalase and respiratory activities, results similar to those found by Appleman in potato tubers. The curves of the oxidase activities, however, do not conform to either of these. Our results seem to confirm Appleman's, that catalase is more significant in respiration than are oxidases.

EFFECT ON PHOTOSYNTHETIC ACTIVITY

Inasmuch as the photosynthetic activity of a plant may be checked temporarily or permanently by heat, asphyxiation, or anesthetics (8, 9), and as hydrocyanic acid influences the respiration of the plant, it was naturally concluded that the cyanid might affect photosynthesis. With a view to ascertaining this point, the appearance and disappearance of starch in tobacco (*Nicotiana tabacum*) and geranium (*Pelargonium* spp.) was followed. The test for starch was made by steeping leaves in boiling water for a moment, then immersing in warm alcohol to extract the chlorophyll, after which they were placed in weak iodin solution. The plants to be tested were placed in the dark for 24 hours, or until a starch test on the leaves was negative. When free from starch, the plants were divided into two sets, one of which was fumigated in a tight box in the dark; the normal set was also kept in the dark during the fumigation. The dose was 1 gm. of potassium cyanid per cubic meter, for one hour in the case of the tobacco, and for one and a quarter hours in the case of the geranium. At the close of the fumigation both sets were brought into the light. A strong starch test was obtained in the normal plants within an hour, but the fumigated tobacco required 5.5 hours, and the geranium 5 hours before even a slight starch test was obtained. By evening the starch content was still much less in the fumigated than in the normal. Frequent tests showed that it required about three days for the fumigated plants to recover normal activity. Similar tests were made with potatoes, cucumbers, and tomatoes, with like results. It is noteworthy that the first evidence of recovered photosynthetic activity corresponds in general to the periods of recovery of the catalase and the respiratory activities.

EFFECT ON TRANSLOCATION OF FOOD MATERIALS

It was observed in the above experiments that the fumigated plants were not able to use up during the night even the small amount of starch that had been formed up to the previous evening. Evidently the trans-

location, as well as the manufacture of starch, is interferred with by hydrocyanic-acid fumigation.

To confirm this point, tomato plants were placed in bright sunlight until in the afternoon they showed a high starch content. A number of these plants were fumigated in the sunlight with 1 gm. of potassium cyanid per cubic meter for 1.25 hours, the control also remaining in the sunlight. At the close of the fumigation both sets were placed in the dark. Eighteen hours later the unfumigated plants showed that about three-fourths of the starch had been removed. The fumigated, however, showed apparently no diminution in starch content. Six hours later the normal gave but a feeble starch test, while the fumigated set still gave a strong test. It required from 3 to 3.5 days for complete disappearance of starch in the fumigated plants. Similar trials were carried out with other sets of tomatoes and with geraniums, with confirmatory results

There are two possible explanations of the inability of the plant to remove its starch after submission to the influence of hydrocyanic acid. One is the inhibition of the diastases, the other is the inhibition of the oxidation of sugars in the growing parts of the plant, which would tend to maintain the concentration of sugar in the leaves and stems, and thus prevent the hydrolysis of starch.

In regard to the first possibility, it has already been mentioned under nonrespiratory enzyms that diastases are not affected by hydrocyanic acid. To test the point more accurately, leaf powders were prepared from fumigated and unfumigated leaves, and their diastatic activity tested quantitatively. One gm. of each of the powders liberated enough sugar from soluble starch to reduce 1.04 gm. of copper in Fehling's solution. Hence, there is no detectable effect of hydrocyanic acid on this enzym.

The inhibition of sugar oxidation was determined in the following way. A large geranium, plant containing two branches of about equal size was selected. About 5 inches of the growing shoot of one branch was inserted into a fumigation box through an opening, which was then sealed tight. This shoot was fumigated with 1 gm. of potassium cyanid per cubic meter for one hour. The plant was then placed in complete darkness, and from time to time leaves were removed for a starch test. The leaves in the normal branch lost all their starch within 24 hours. The basal leaves of the branch the tip of which had been fumigated required 48 hours for complete removal of starch. This shows that the translocation phenomenon brought about by hydrocyanic-acid fumigation centers in the growing parts, and thus is primarily a failure of the oxidation of food materials in those regions. A few days later it was noticed that the axillary buds of the leaves below the fumigated portion were awakened into growth just as if the growing shoot had been pruned. After attaining a length of about ½ inch, their further growth was prevented by the recovery of the terminal shoot.

EFFECT ON THE COMPOSITION OF THE PLANT

In view of the fact that the hydrocyanic acid absorbed by the plant is decomposed in the tissues, that the metabolism of the plant is changed because of the disturbed enzym equilibrium, and that several plants have been shown to utilize the nitrogen of the cyanid group (7, 14, 18), it was thought advisable to determine whether there was any change in the composition of tomato plants due to cyanid fumigation.

Six uniform groups of 30 tomato plants were selected and fumigated in different ways, as described in Table II. After six weeks of growth they were cut off at the ground and the fresh weight, dry weight, percentage of ash, and percentage of protein determined for each set. From an examination of the data, it will be seen that there is no apparent change in the gross composition of these plants due to any combination of fumigation doses.

TABLE II.—*Analysis of six sets of tomato plants fumigated with hydrocyanic acid, arranged in order of their total dry weight*

Set No.	Treatment.	Weight of plants.		Ash.	Protein.
		Fresh.	Dry.		
		Gm.	*Gm.*	*Per cent.*	*Per cent.*
11	1 fumigation, 0.25 gm. of potassium cyanid per cubic meter overnight	1,463	140	21.22	14.31
10	3 fumigations, 0.25 gm. of potassium cyanid per cubic meter overnight, 2 weeks apart	1,295	123	16.45	16.84
12	1 fumigation, 1 gm. of potassium cyanid per cubic meter for 1.5 hours in daylight	1,174	120	19.95	14.28
14	1 fumigation, 0.5 gm. of potassium cyanid per cubic meter overnight	1,089	106	20.40	14.18
15	Control, not fumigated	1,101	103	21.88	14.37
13	9 fumigations, 0.25 gm. of potassium cyanid per cubic meter overnight, 3 to 4 days apart	944	95	21.00	14.28

EFFECT ON THE GROWTH OF THE PLANT

Townsend (20) has shown that there is an increase in germination in seeds fumigated with hydrocyanic acid. Woodworth (25) found that scale insect eggs fumigated with a sublethal dose of hydrocyanic acid resulted in their earlier hatching. Many of the fruit growers of the West are convinced that whether their trees are infested with insects or not they will not receive a maximum yield unless they have been given cyanid fumigation. A similar stimulation in the growth of plants may be noted in Table II, where four fumigated sets at the close of the fumigation exceeded in dry weight the normal set. In this experiment very frequent fumigation, with a consequent constant disturbance of photosynthetic activity, resulted in a diminished dry weight.

To obtain more definite data on this point, a longer experiment with tomatoes was conducted, carrying them through their complete life cycle. Three sets (No. 16, 17, and 18) were selected according to uniformity in size and vigor. Wooden boxes 16 inches square and 12 inches deep were filled with rich soil and six plants in each allowed to attain a height of about 6 inches before the experiment was started. There were 10 boxes in each set. Set 16 was kept as a control. No. 17 was fumigated with 1.5 gm. of potassium cyanid per cubic meter for one hour during the night, with curtains drawn tightly. The effect of the fumigation was a severe curling of the leaves and a burning of the youngest leaves (Pl. 34, A). No. 18 was fumigated three times at two-week intervals with 0.25 gm. of potassium cyanid per cubic meter overnight. No injury resulted from any of these. Each week from three to six plants from each set were taken, and their dry weight was determined. The growth curves in figure 7 give these data. The plants were controlled to one growing stem, and at the end of seven weeks had reached the top of the greenhouse. The plants were now limited to one in a box and nine boxes to the set (Pl. 34, B).

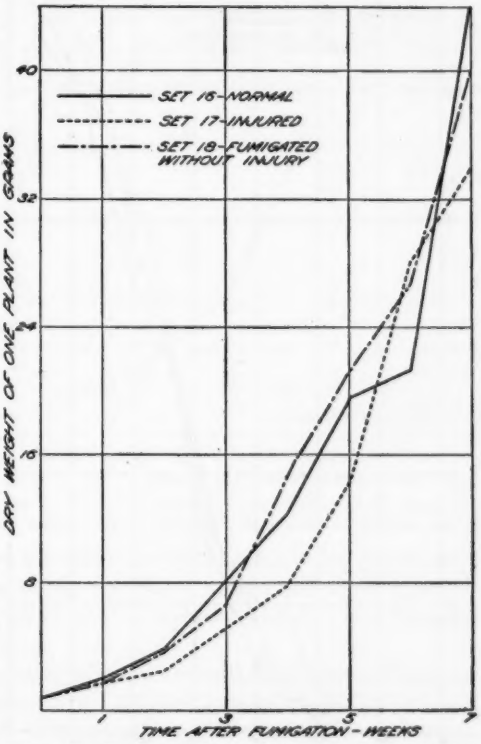

FIG. 7.—Growth curves of three sets of tomato plants as affected by hydrocyanic-acid fumigation.

As it was decided to follow the subsequent history of the sets by the quantity of ripe fruit produced, the growing point was cut off and all adventitious buds kept removed. Later, when the green fruit had begun to set, a number of large leaves from each plant were removed to admit more light. The daily production of ripe fruit is shown in figure 8. Attention should be called to the fact that set 18, fumigated without injury, produced fruit two weeks earlier than the normal, and that almost throughout the experiment both fumigated sets had a higher

yield of fruit than the normal. At the close of the experiment the total weight of ripe fruit was less for the normal than for either of the fumigated sets.

It was thought desirable to obtain similar data on a quick-growing plant like lettuce. Small plants were set into boxes similar to the ones used in the above experiment with tomatoes, and divided into three sets. No. 19 was a normal set. No. 20 was fumigated with 0.25 gm. of potassium cyanid per cubic meter overnight, without apparent injury. No. 21 was fumigated with the same dose for one hour in bright sunlight. This set was severely injured, almost all of the mature leaves being burned. Samples for the determination of dry weight were taken every three to five days until the plants were fully grown. The data obtained are expressed graphically in figure 9. There appears to be practically no difference between the normal and the set fumigated without injury. The set which was severely injured was noticeably retarded, but soon recovered its power of growth and reached maturity about one week after the two other sets.

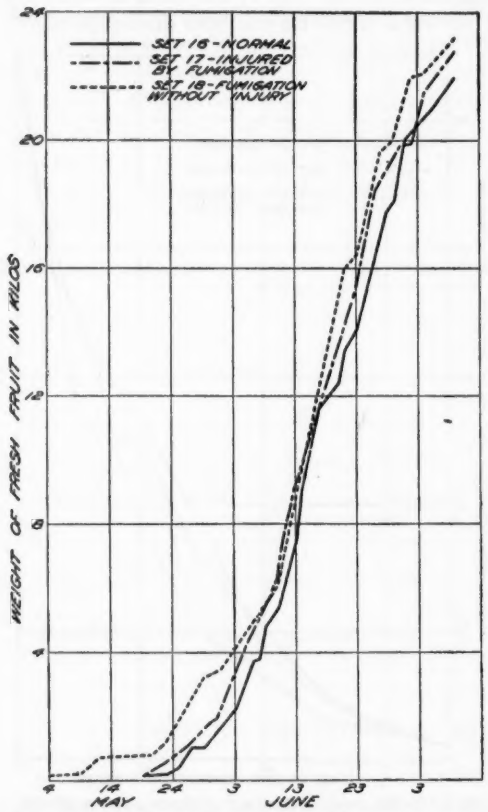

FIG. 8.—Curves showing the production of fruit by the three sets of tomato plants in figure 7.

From these results it appears that the growth factor in tomatoes at least is stimulated by hydrocyanic-acid fumigation. This is manifested not only in total dry weight of plants but in ripe fruit produced as well. These experiments further show that in greenhouse practice severe injury to plants may be not so serious as might appear, since the plants, after a temporary setback, grow with increasing vigor to maturity.

EFFECT ON PERMEABILITY OF THE LEAF

In the work of the Armstrongs (3) on hormones and anesthetics and their effect on permeability in plants, they distinguished between the action of hydrogen cyanid and that of the typical anesthetics. The latter disturbs the osmotic relations (and hence permeability) and brings enzyms and their substrates together more rapidly, while cyanid affects the enzyms directly, especially the ones concerned in pigment formation (the oxidases). Osterhout (16), using electrical conductivity as a measure of permeability, has demonstrated that both anesthetics and hydrogen cyanid cause at first a decrease in permeability, followed shortly by a rapid increase. This decrease is reversible if the anesthetic be removed. If the anesthesia be carried too far, however, it is followed by an increase in permeability which is irreversible. The change from one to the other probably represents the death point of the cells. When the Armstrongs (4) immersed leaves of *Prunus* sp. in water, the leaves gained slightly in weight, but lost sugar to the solution; if chloroform or ether was added to the water, the leaves gained still more in weight. When cyanid was used, there was no increase in weight; and the leaves lost no sugar to the solution.

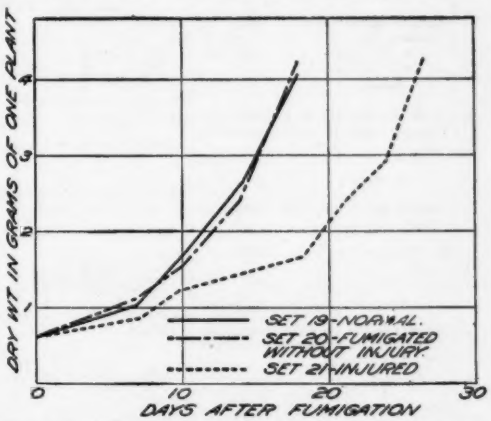

FIG. 9.—Growth curves of three sets of lettuce plants, showing the effect of light and severe fumigation with hydrocyanic acid.

To determine whether fumigation with cyanid affects permeability, and in which direction, the work of the Armstrongs was repeated with tomato leaves. The leaf blades were cut off, washed in distilled water, dried between blotting paper, and weighed. They were then immersed about two-thirds their length in a measured volume of the solution to be tested and allowed to stand the specified time. After drying and weighing, they were exposed freely to the air for an hour and weighed a third time. After the removal of the leaves, the solutions were tested with Fehling's solution for the approximate amount of reducing sugars lost by the leaves under various treatments. The results are exhibited in Table III.

TABLE III.—*Permeability of tomato leaves under the influence of ether, chloroform, potassium cyanid, and hydrocyanic acid*

No.	Material and treatment.	Original weight.	After treatment.		After exposure to air for one hour.		Sugar test in water after removal of leaves.
			Weight.	Change in weight.	Weight.	Change in weight.	
		Gm.	*Gm.*	*Per ct.*	*Gm.*	*Per ct.*	
1	Normal leaves in distilled water, 18 hours.	0.1933	0.1975	+ 2.1	0.1565	−19.0	Very faint positive.
2	.....do	.2077	.2074	.0	.1330	36.0	Do.
3	.....do	.2755	.2750	.0	.2312	16.0	Do.
4	.....do	.1432	.1476	+ 2.9	.1074	25.0	Do.
	Average			+ 1.25		−24.0	Do.
5	Normal leaves in ether water, 18 hours.	.1960	.1872	− 4.5	.1392	34.0	Faint positive.
6	.....do	.1278	.1248	− 3.1	.0907	30.0	Do.
7	.....do	.2913	.2750	− 5.6	.1810	37.0	Do.
	Average			− 4.4		34.0	Do.
8	Normal leaves in a solution containing 2.4 mgm. of potassium cyanid per c. c.; 18 hours.	.2807	.2610	− 7.0	.1530	45.0	Negative.
9	.....do	.2644	.2433	− 8.0	.1478	44.0	Do.
	Average			− 7.5		44.0	Do.
10	Normal leaf in chloroform water, 18 hours.	.1408	.1200	−14.7	.0850	−39.0	Strong positive.
11	Normal leaves in water, 22 hours	.1210	.1195	− 1.2	.1075	11.1	Faint positive.
12	.....do	.0903	.0912	+ 1.0	.0820	9.2	Do.
13	.....do	.2278	.2228	− 2.2	.2100	− 8.0	Do.
	Average			− 0.8		− 9.4	Do.
14	Normal leaves in water containing 0.70 mgm. of hydrocyanic acid per c. c.; 22 hours.	.1708	.1358	−20.0			Negative.
15	.....do	.0720	.0500	−30.0	.0280	61.0	Do.
16	.....do	.1148	.0910	−20.0	.0735	36.0	Do.
	Average			−24.0		−32.0	Do.
17	Normal leaves in water containing 0.35 mgm. of hydrocyanic acid per c. c.; 22 hours.	.1112	.0848	−23.0			Do.
18	.....do	.1302	.0912	−30.0			Do.
19	.....do	.1543	.1010	−34.0	.0658	57.0	Do.
	Average			−29.0		−57.0	Do.
20	Leaves from plants fumigated one hour previously with 1.0 gm. of potassium cyanid per cubic meter, immersed in water 22 hours.	.2188	.2277	+ 4.0	.2065	5.6	Faint positive.
21	.....do	.0700	.0571	−18.4	.0476	32.0	Do.
22	.....do	.1012	.0928	− 8.3	.0842	16.8	Do.
	Average			−10.0		−18.0	Do.
23	Normal leaves in water 24 hours	.2253	.2133	− 5.3			Do.
24	.....do	.1375	.1335	− 3.0			Do.
25	.....do	.0831	.0821	− 1.2			Do.
26	.....do	.0500	.0360	−28.0			Do.
	Average			− 9.0			Do.
27	Normal leaves in water containing 0.10 mgm. of hydrocyanic acid per c. c.; 24 hours.	.0793	.0710	−10.5			Negative.
28	.....do	.1250	.1141	− 8.7			Do.
29	.....do	.0416	.0277	−33.4			Do.
	Average			−17.0			Do.
30	Leaves from plants fumigated one hour previously with 1.0 gm. of potassium cyanid per cubic meter in water 22 hours.	.1853	.1603	−13.0			Faint positive.
31	.....do	.1167	.1021	−12.0			Do.
32	.....do	.0222	.0158	−29.0			Do.
	Average			−18.0			Do.

Contrary to the findings of the Armstrongs, there was no gain in weight from the absorption of water. There was always a loss in weight, but this was less marked in normal leaves than in fumigated leaves, and when ether or chloroform, and more especially potassium or hydrogen cyanid were used, the loss was very pronounced. Fumigated leaves immersed in water showed less effect than normal leaves in a solution of hydrocyanic acid. Although the successive decrease and increase in permeability noticed by Osterhout could not be detected by this method, the very marked increase in the case of the leaves soaked in a solution of hydrocyanic acid no doubt indicates that the "irreversible increase" has been attained. Also, when leaves are "burned" in cyanid fumigation, it means that the "differential septa" have lost their power of differentiation, and they are disintegrated and the tissue is dead.

No explanation is offered for the failure of all the leaves under the influence of cyanid in Table III to lose sugar to the surrounding medium. One would expect the reverse from the fact, first, that respiration is below normal, and, hence, sugar is not used up; second, that diastases are not prevented by prussic acid from forming more sugar; and third, that the sugar if present can escape into the surrounding medium more readily because of the more permeable septa.

EFFECT ON TRANSPIRATION

Having shown that hydrocyanic-acid fumigation brings about an increased permeability in the leaf septa, the writers thought it desirable to ascertain how this is related to the wilting effects noticed in fumigation injury.

Water was withheld from a number of potted tomato plants until the wilting point was reached. On assuming that this gave all the pots about the same water content, 250 c. c. of water were added to each and the pot and soil surface thoroughly paraffined. After a preliminary test to show that all the plants transpired at about the same rate, half of them were fumigated. The dose and length of fumigation were varied to produce different degrees of injury. The controls were kept under similar conditions in each case. After fumigation the plants were removed to the greenhouse and weighed at intervals to follow the loss in water by transpiration.

The results are shown graphically in figure 10. Contrary to what was expected the fumigated plants in every case exhibited a diminished transpiration. The more severe the injury, the greater was the wilting effect and the less was the transpiration. In addition, stomatal measurements disclosed the fact that after fumigation, whether the plants were in the light or in the dark, the stomata rapidly closed. Recovery to normal transpiration required 24 to 36 hours in the case of plants lightly fumigated; severely injured plants, of course, never recovered.

The explanation of this phenomenon is, no doubt, that the inhibited photosynthetic and respiratory activities, together with the increased permeability of the cell walls, occasion the closing of the stomata. This reduces stomatal transpiration more or less completely. Cuticular transpiration, however, can continue as usual; in fact, with the increased permeability of the leaf septa, it might even be augmented. In order to demonstrate the hypothesis, two groups of tomato plants were kept in

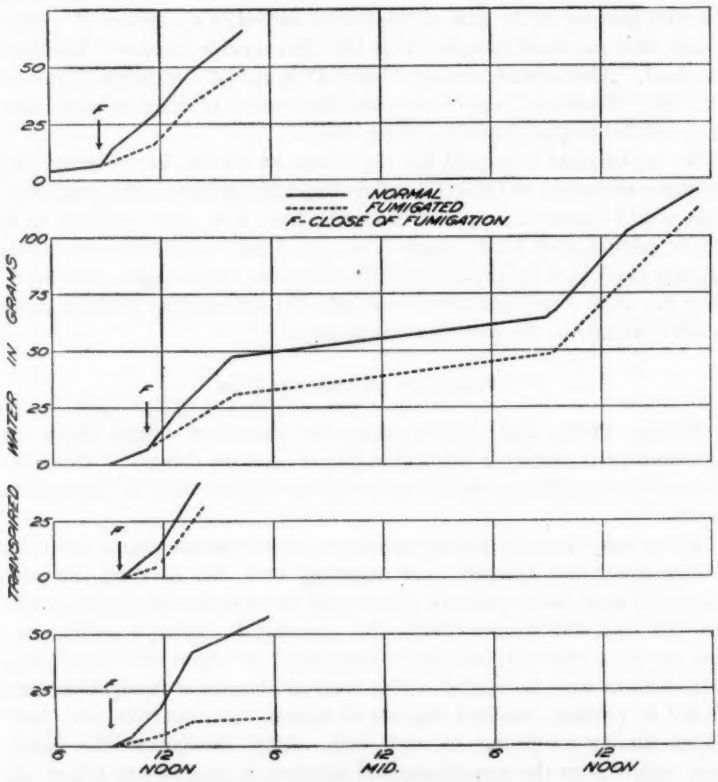

FIG. 10.—Transpiration curves of tomatoes as affected by hydrocyanic-acid fumigation. Arranged from top to bottom in order of increasing injury.

absolute darkness before, during, and after fumigation. The loss in water under these conditions represents loss through the cuticle of the leaves, since the stomata are closed. The curves in figure 11 show that there is a considerable increase in this phase of transpiration in the fumigated plants. Meanwhile the increased permeability has resulted in decreased osmotic pressure in the tissues, which would slacken, or stop altogether, the inflow of water from the stems. Consequently the water

exchange in the leaf is in favor of the cuticular transpiration, and wilting results. If the disturbance in the osmotic relations does not reach the stage of "irreversible increase in permeability" described by Osterhout (16), the leaf will in time recover its normal turgescence. If it exceeds that point, however, the leaf is "burned" and dies, as was discussed above under permeability.

In order to demonstrate in another way that the septa of injured leaves are made equally permeable to solutes and to solvent, or, in other words, are "permeable" instead of "semipermeable," the experiment was tried of forcing water into wilted plants to cause them to recover their turgidity (17, p. 232). A plant was cut off at the base and the stem sealed into one arm of a U-tube. This arm was filled with water and the other with mercury. Normal tomato plants so wilted that they had bent completely over were forced into an upright turgid condition by 12 cm. of mercury within 10 minutes. Plants wilted by hydrocyanic acid, however, did not respond to the treatment. The less injured leaf blades would partly recover, and the petioles completely; the more severely injured blades would remain limp and gradually curl and shrivel, and the "burned" petioles also would fail to respond even slightly to the pressure.

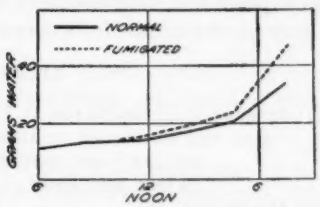

FIG. 11.—Curves showing the cuticular transpiration of fumigated and of normal tomato plants.

CONCLUSIONS

From the data presented it may be stated that plants subjected to hydrocyanic-acid fumigation absorb more or less of the gas; that the immediate effect of the presence of this poison is a reduction in the activity of the oxidases and catalase, and, hence, in respiratory activity. Resulting from this is an inhibition of photosynthesis and translocation of carbohydrate, and a closing of the stomata. Another result is an increase in the permeability of the leaf septa, which causes less rapid intake of water from the stems and more rapid cuticular transpiration. In cases of mild fumigation this results in merely a temporary wilting; in more severe fumigations the wilting is followed by disintegration and death of the tissues. This increased permeability is no doubt due to the reduced respiratory activity. Budgett (5) has shown that changes in the permeability in protozoa treated with cyanid are similar to those produced by lack of oxygen. Within a few hours after fumigation the oxidase activity has returned to normal, while the catalase and the respiratory activities have exceeded the normal. By this time the recovery of photosynthetic action is first apparent; complete recovery, however, of this and of translocation of food material is not attained before from two to three days. Respiration remains above normal for

several days. If the increase in permeability is not so severe as to cause the death of the tissues, recovery is followed in many cases by a rate of growth and of fruit production (in the tomato) in excess of the normal. Hence, in greenhouse practice it is unwise to condemn injured plants too quickly. The stimulation of growth may be due to at least two factors—namely, to the increased activity of the catalase which Zieger (26) found to be proportional to general metabolic activity in animals, and to the increased permeability of the cell walls, allowing readier exchange of food materials and of gases. It is very improbable that the extra nitrogen of the cyanid has anything to do with increased nutrition, as is suggested by Woodworth (25) in the case of scale insect eggs.

In short, then, the primary effect of the presence of hydrocyanic acid in a plant is a disturbance of the oxidase and catalase activities. All other physiological effects appear to be secondary to these.

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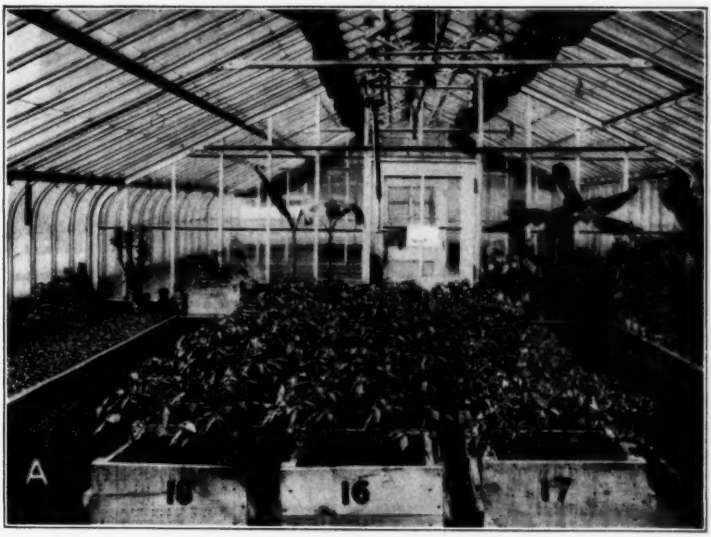
PLATE 34

A.—Tomato plants in the greenhouse at beginning of growth experiment. Note the curling of leaves in set 17.

B.—Tomato plants when in fruit, showing the method of handling.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EFFECT OF PUMPING FROM A SHALLOW WELL ON THE GROUND-WATER TABLE[1]

By WALTER W. WEIR,
Assistant Professor of Soil Technology, California Agricultural Experiment Station

INTRODUCTION

In many of the irrigated sections of California the ground-water table has reached a point so near the surface that drainage is required. The usual methods of tile or underdrainage have in some instances proved expensive, especially where gravity outlets are not readily available. As a possible means of reducing the cost of drainage the suggestion has been made that equally satisfactory results might be secured by pumping from a shallow well into which the water from the surrounding area was allowed to seep without the use of tile. If adequate drainage could be secured by this method, it would be especially applicable in those sections where pumping is necessary to secure an outlet for tile drains and where the drainage water thus developed is needed for irrigation or alkali reclamation.

In order to obtain more definite information on the effect of pumping from a shallow well on the ground-water table and its relation to the drainage of irrigated lands, the experiment described in the following pages was undertaken at the Kearney Park Experiment Station, Kearney Park, California.

SOIL

The site for the pumping plant was chosen because it represented soil and culture conditions typical of a large area about Fresno. The land on three sides of the pumping plant was farmed and irrigated according to the usual practices in that vicinity, while on the fourth side it was more intensively cultivated and less frequently irrigated, owing to the experimental nature of the work carried on.

The soil is mapped by the Bureau of Soils[2] as the Madera fine sandy loam and is of fairly uniform texture from the surface to a depth of 7 feet. The excavation for the sump was made in December, 1913, this being the month when the water table is lowest. The soil was dry on the surface, but quite wet at 7 feet in depth. At from 7 to 8 feet a layer of grayish-colored hardpan was encountered, which, however, was seamy

[1] Based on work done under a cooperative agreement between the Office of Public Roads and Rural Engineering, United States Department of Agriculture, and the University of California Agricultural Experiment Station.

[2] STRAHORN, A. T., NELSON, J. W., HOLMES, L. C., and ECKMANN, E. C. SOIL SURVEY OF THE FRESNO AREA, CALIFORNIA. *In* U. S. Dept. Agr. Bur. Soils Field Oper. 1912, [14th Rpt.], p. 2089-2166, fig. 56 pl. 29-31, A (col.). 1915.

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and easily excavated. Below the hardpan was found a layer of coarse sand 1 foot in thickness, which contained water. From 9 to 12½ feet a very dense, brown, iron-cemented hardpan was found, which, although somewhat seamy, was excavated with difficulty on account of the water. From 12½ to 13½ feet a second layer of coarse water-bearing sand was found. At 13½ feet a third layer of hardpan was encountered, but its nature and thickness were not determined. Later a 4-inch hole was bored through this hardpan to the loose material below.

METHOD OF PROCEDURE

The sump, which was approximately 6 feet square and 13½ feet deep, was cribbed with 3 by 6 inch redwood lumber and a ½-inch space was

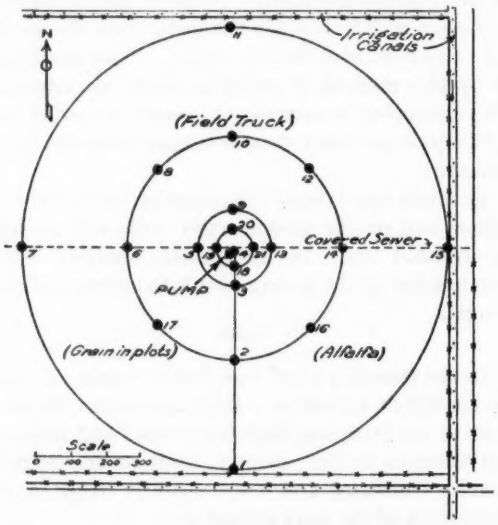

FIG. 1.—Plan showing location of irrigation canals and test wells with reference to the pumping plant.

left between planks so that the lateral movement of the water would not be retarded.

The pumping equipment consisted of a 3-inch centrifugal pump of the vertical type, having the suction about 13 feet below the surface, and operated by a 5-horsepower belt-connected motor controlled by an automatic float switch.

Test wells of 3-inch galvanized-iron pipe, 8 feet deep, were located along lines extending in the four cardinal directions from the pump. The first wells were 100 feet, the second 300 feet, and the third 600 feet distant from the pump. On the diagonals wells were placed 300 feet from the pump, thus making eight wells on a radius of 300 feet and four at each of the other distances. One test well was located just outside

the pump house and can be considered as being zero distance from the sump. Later, four more test wells were located 50 feet from the pump. Observations on these last four wells (No. 18, 19, 20, and 21) were not complete, as these wells were not cased and did not remain open during the entire season. Figure 1 shows the location of the test wells with reference to the pump and irrigation ditches, and the cultural features of the vicinity.

In March, 1914, observations were begun by noting the depth to water in the various test wells at intervals of a week. In April the pump was

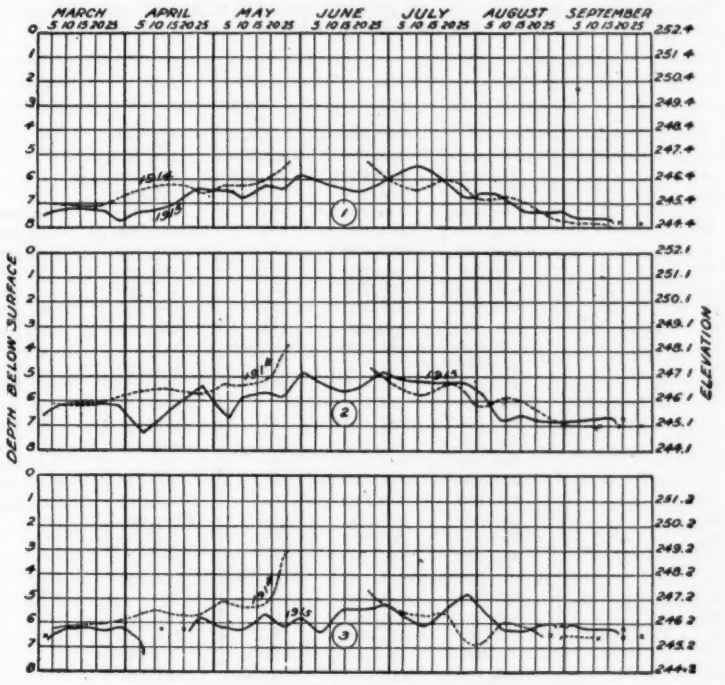

FIG. 2.—Ground-water curves for 1914 and 1915 (wells 1, 2, and 3).

started, but was kept in operation only a short time. On three or four occasions during the irrigation season the pump was run for a day or two. After about an hour's pumping the water would be entirely removed from the sump and the pump would stop for two or three minutes while the sump was being refilled to a height sufficient to start the motor. After the first lowering only two or three minutes were required to empty the sump. About 250 gallons were discharged during each pumping period.

It was soon found that an intermittent flow of such a small quantity of water was not sufficient to irrigate economically even the small demonstration plots of the Experiment Station; and, as no other provision was made for disposing of the discharge, very little pumping was done during the year. Observations were continued with reasonable regularity on the various test wells, the profiles of which are shown in figures 2 to 7. The pump was in operation for so short a time and the amount of water pumped was so small that there was no appreciable effect on the ground-water table, even in the immediate neighborhood of the pump.

TABLE I.—*Daily pump discharge (in gallons) from April to August, 1915, at Kearney Park Experiment Station*

Day.	April.	May.	June.	July.	August.
1	.....	125,600	145,800	133,100	(a)
2	.....	125,000	145,800	125,700	(a)
3	113,000	120,800	142,000	115,200	(a)
4	103,300	122,700	132,400	136,900	(a)
5	103,300	122,700	(b)	112,900	122,700
6	104,000	125,600	(b)	111,400	118,200
7	100,200	120,800	(b)	125,700	108,500
8	98,500	129,600	(b)	118,200	105,500
9	101,700	128,800	(b)	112,900	105,500
10	101,700	128,800	(b)	115,200	103,100
11	c 81,000	130,000	(b)	119,700	101,800
12	101,700	124,200	132,300	115,200	98,000
13	104,000	122,700	(d)	111,400	95,000
14	101,000	129,600	(d)	109,200	92,800
15	101,700	128,800	(d)	110,000	98,000
16	100,000	128,100	(d)	112,200	87,500
17	101,000	125,600	(d)	112,200	85,300
18	102,800	128,800	(d)	(a)	c 41,800
19	103,400	135,500	(d)	(a)	c 40,300
20	121,800	128,800	(d)	c 98,500	c 40,000
21	197,000	128,800	(d)	c 105,600	(e)
22	200,000	128,800	(d)	111,500	(e)
23	164,200	130,000	(d)	107,000	(e)
24	161,800	132,500	(d)	c 54,200	(e)
25	158,600	128,800	(d)	(a)	(e)
26	144,500	143,000	(d)	c 80,000	(e)
27	156,300	139,300	(d)	115,200	(e)
28	c 74,000	133,300	(d)	c 76,300	(e)
29	138,500	143,000	c 71,800	124,200	(e)
30	137,800	140,800	133,000	125,700	(e)
31	.....	140,800	.....	124,200	(e)
Total	3,376,800	4,012,600	903,100	3,119,500	1,550,300
Total for season	.....	.....	.....	.....	12,791,300

[a] Pump not running.
[b] Belt broken.
[c] Pump in operation only a portion of the day.
[d] Motor disabled.
[e] Pumping discontinued.

The profiles showing the water-table curves for 1914, therefore, represent very nearly normal conditions as they would have been had no pumping been done.

During 1915 much more complete data were obtained. The observation wells were measured weekly from the beginning of the irrigation season in March until they were all dry in September. The pump was run continuously, and daily records were made of the discharge from April 3 to August 21, except during about three weeks in June, when

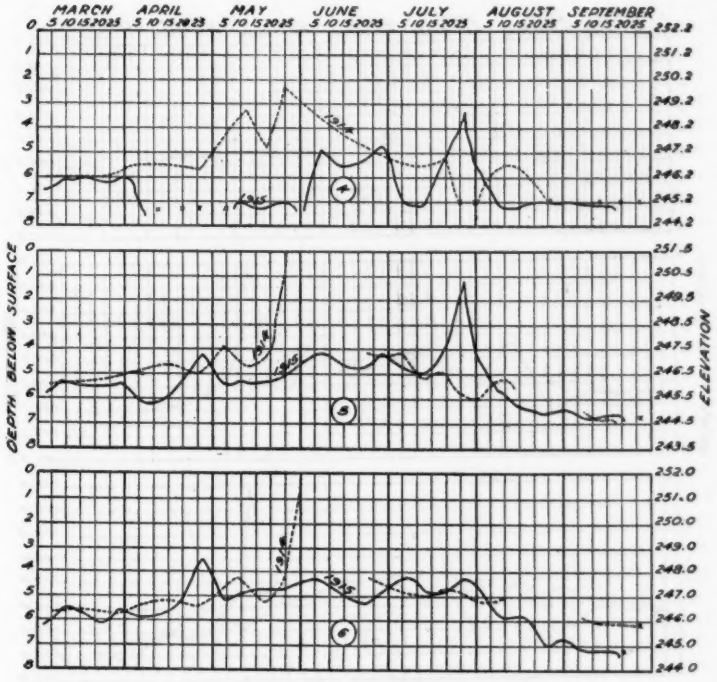

FIG. 3.—Ground-water curves for 1914 and 1915 (wells 4, 5, and 6).

the pump was dismantled for repairs. The weekly well readings for 1915 are plotted with those for the previous year in figures 2 to 8, and the daily pump discharge is shown in Table I. The data obtained during 1915 have been plotted separately for each month in figures 9 to 15, inclusive, showing the slope of the ground water along the different lines passing through the sump.

INTERPRETATION OF RESULTS

Observations taken at other places in the vicinity of Fresno covering a period of several years show that the ground water normally reaches its highest point during June. The rise up to this date is somewhat irregular, owing to irrigation and a somewhat fluctuating flow in the irrigation canals. The decline in the water-table curve after June is more regular and continuous until after the rainy season is well advanced in January or February. This condition is not so marked in the data shown in

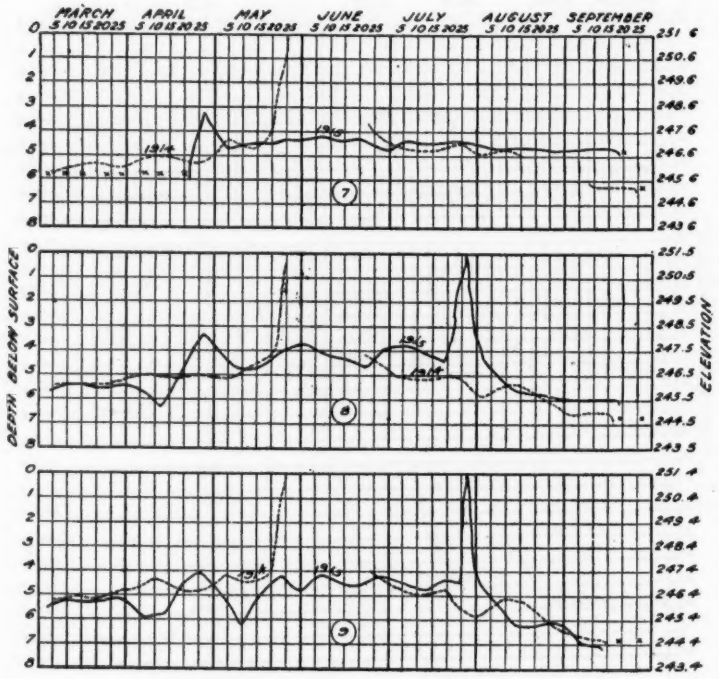

FIG. 4.—Ground-water curves for 1914 and 1915 (wells 7, 8, and 9).

figures 2 to 8 as it probably would have been if the area covered by these observations had been larger. Local irrigations and variations in flow in the canals near by are responsible for the sudden rises and falls in the curves shown.

On April 3, 1915, when the pump was started, the water table averaged slightly lower than on the corresponding date in 1914. The pump-

ing for the first few days apparently affected the water table over the entire area, but showed a more marked effect in the wells nearest the pump. An irrigation late in April caused a sudden rise in the water table, which, however, had resumed a stable condition by May 5. Although the pump was in continuous operation during May, the water table maintained a rather constant level. In those wells which were 100 feet from the sump the water was about 1 foot lower during May, 1915, than during the same month in 1914. In the wells at a greater distance than 100 feet the difference is very slight.

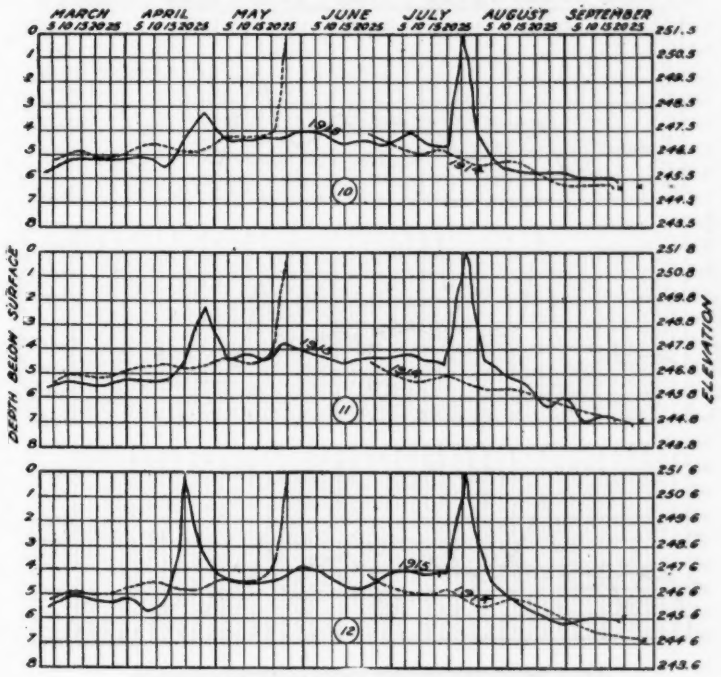

FIG. 5.—Ground-water curves for 1914 and 1915 (wells 10, 11, and 12).

During the week preceding and the week following the first of June, 1915, there was a perceptible rise in the water table over the entire area. It is apparent that this rise was well advanced before the pump stopped on June 4. Although the pump was in operation but one day between June 4 and June 28, there was no further rise in the water table until near the end of this period; in fact, there was a slight lower-

ing about the middle of the month. The rise recorded at the end of June was apparently checked in the wells nearest the pump, but did not reach the maximum in those farther away until the end of the first week in July. An irrigation in July caused a sudden rise followed by a decline which by August 10 had reached a point as low as any during the season. The stopping of the pump from August 1 to August 4 did not check the receding water table. During June, 1915, when the pump was not in operation, the water table averaged lower than during

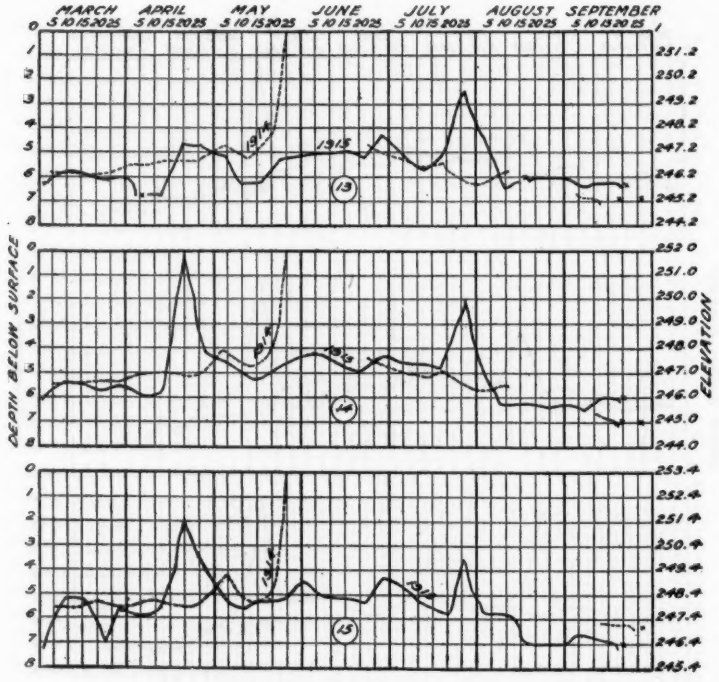

FIG. 6.—Ground-water curves for 1914 and 1915 (wells 13, 14, and 15).

June, 1914, while in July after the pumping was resumed, the water table averaged higher than during the same month of the preceding year. Well 4, which was very near the pump, was affected more than any of the others by variations in the pumping. After August 10 the curves for the two years coincide quite closely.

Figure 9 shows the water table for March, 1915, on four lines through the sump. The pump was not yet started, and the water table was

practically stationary, the curve being nearly a straight line having a slope from north to south. Well 15 on the east-west line shows the effect of water being turned into the irrigation canal.

Figure 10 shows the effect of pumping on the east-west line as far as 600 feet from the sump, while on the north-south line the effect is very slight beyond 100 feet. This is particularly true south of the pump.

Figure 11 shows that during May, the month of maximum pumping, although the water table has a gradual slope from the north and east

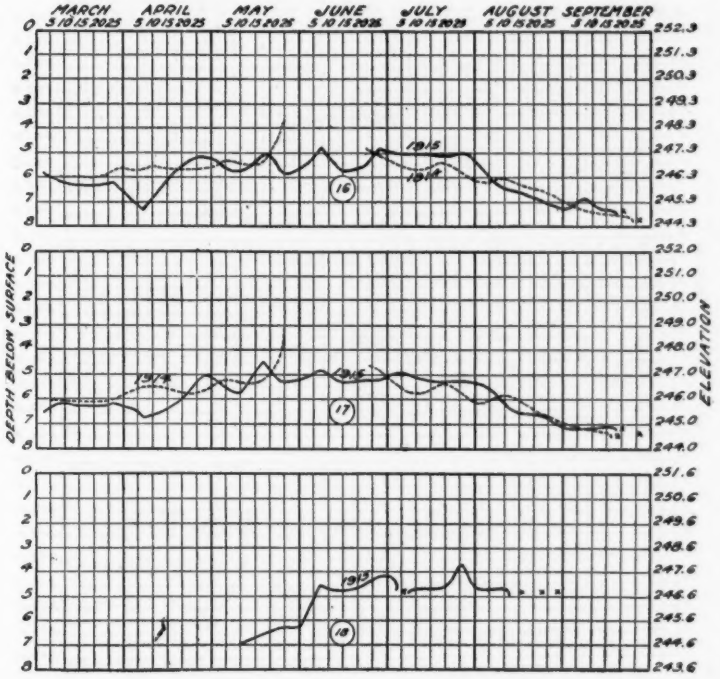

FIG. 7.—Ground-water curves for 1914 and 1915 (wells 16, 17, and 18).

toward the pump, it is approximately parallel to the ground surface. The pump apparently had no effect on the slope of the water table beyond 100 feet. During this month the wells at 50 feet distant from the pump were measured, which, no doubt, gives more accurate curves at these points.

During June the pump was in operation but a short time, and figure 12 indicates that the water table was approximately parallel to but about 2 feet higher than that during March. It will be noted from

figures 11 and 12 that with the exception of these wells 100 feet or less from the pump that the water table is at practically the same elevation. As has already been stated, observations covering a number of years in the vicinity of Fresno show that the water table averages were higher during June than at any other time of the year.

Figure 13 shows results similar to those of the previous ones. The readings on July 19 were taken at the end of a two-day period, in which the pump was idle, and those on the 26th show the effect of the irrigation which was taking place on the fields north of the pump site.

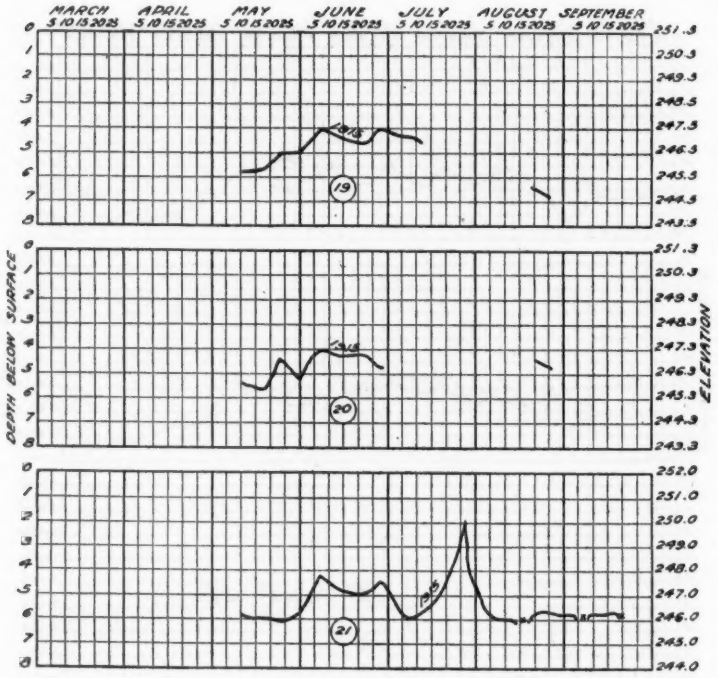

FIG. 8.—Ground-water curves for 1915 (wells 19, 20, and 21).

During August a gradual lowering of the water table is observed, it being lower on each succeeding week than on the previous week. Although the pumping was discontinued on August 20, the curves for August 23 and 30 are not noticeably different in character from those for August 2, 9, and 16.

The September curves are of no special interest except that they indicate a recession of the water table at the 600-foot wells to a point

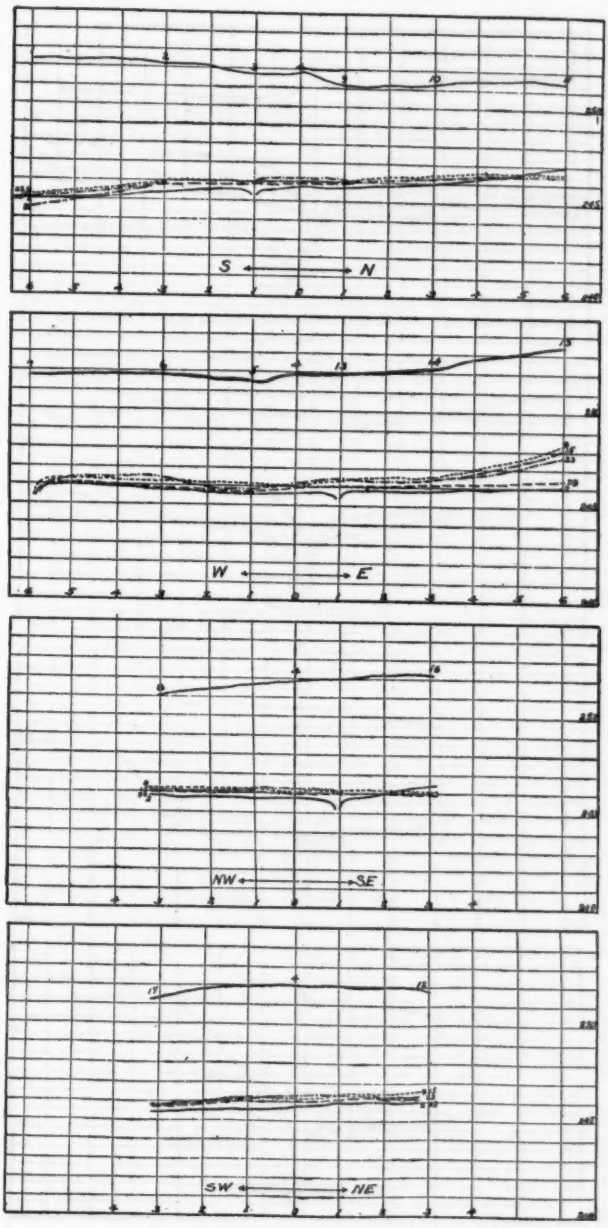

FIG. 9.—Profile of water table during March, 1915.

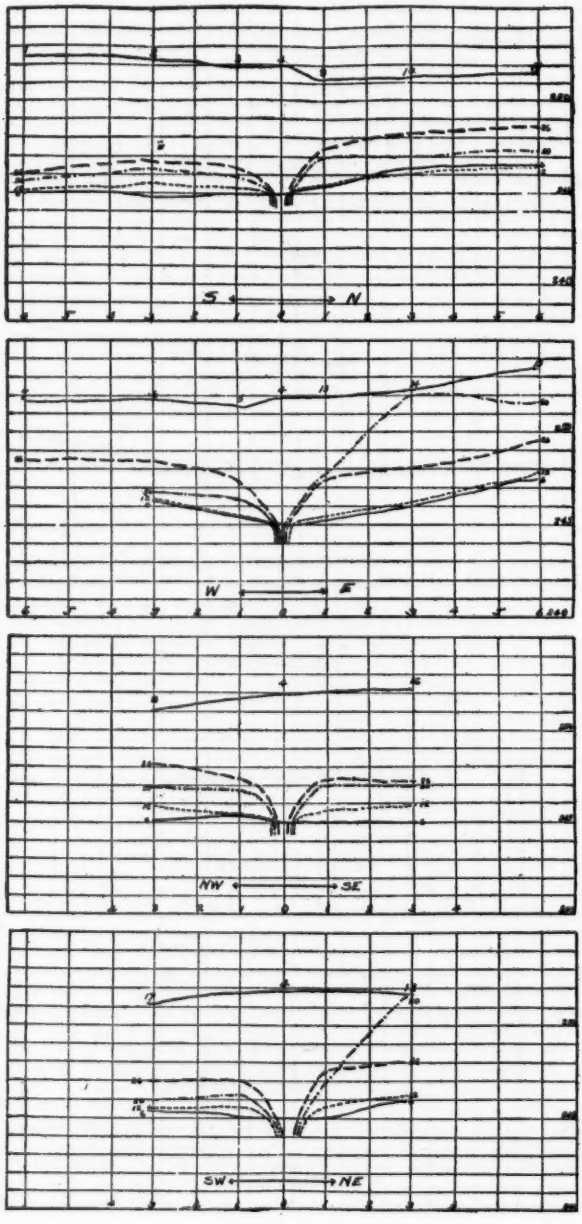

FIG. 10.—Profile of water table during April, 1915.

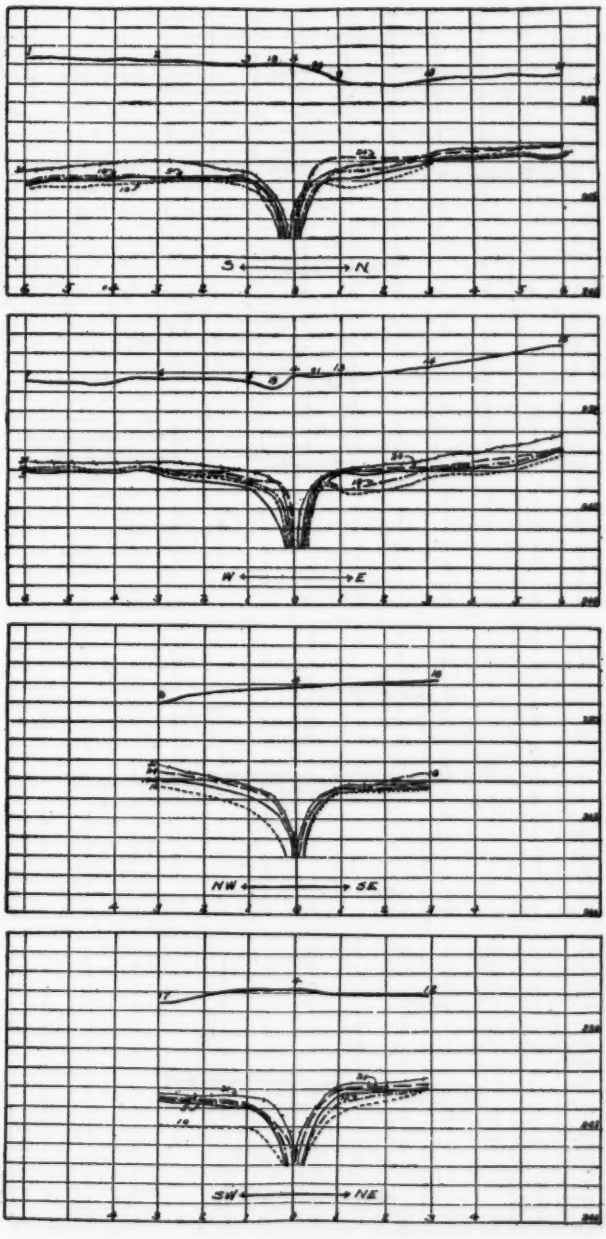

FIG. 11.—Profile of water table during May, 1915.

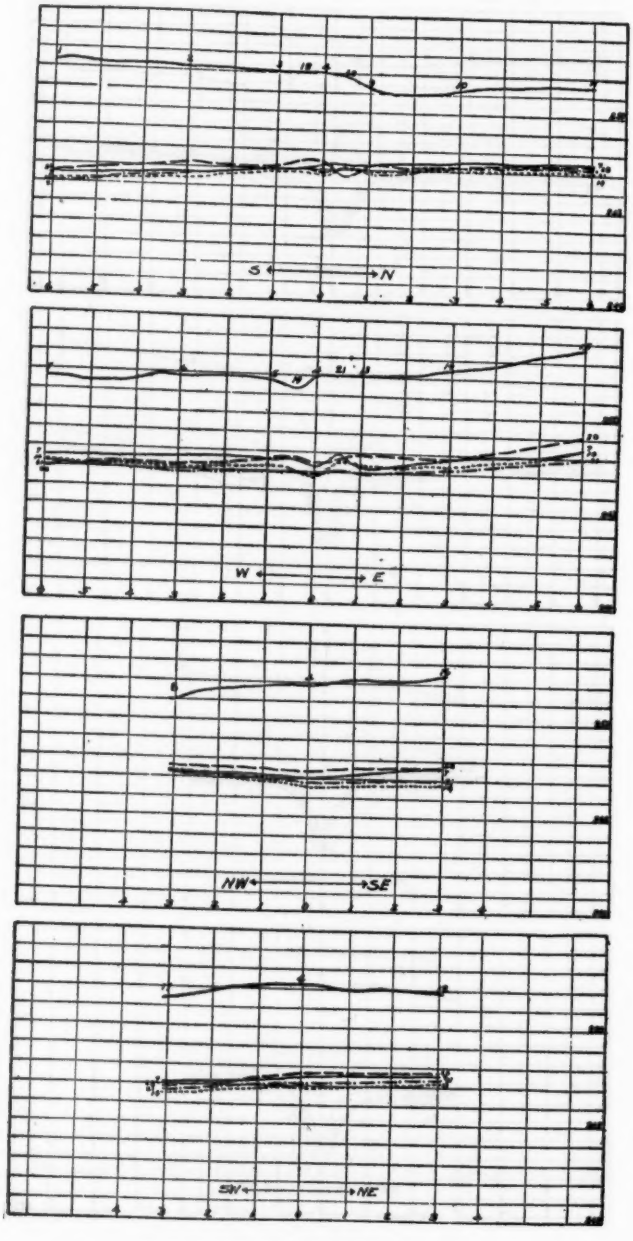

FIG. 12.—Profile of water table during June, 1915.

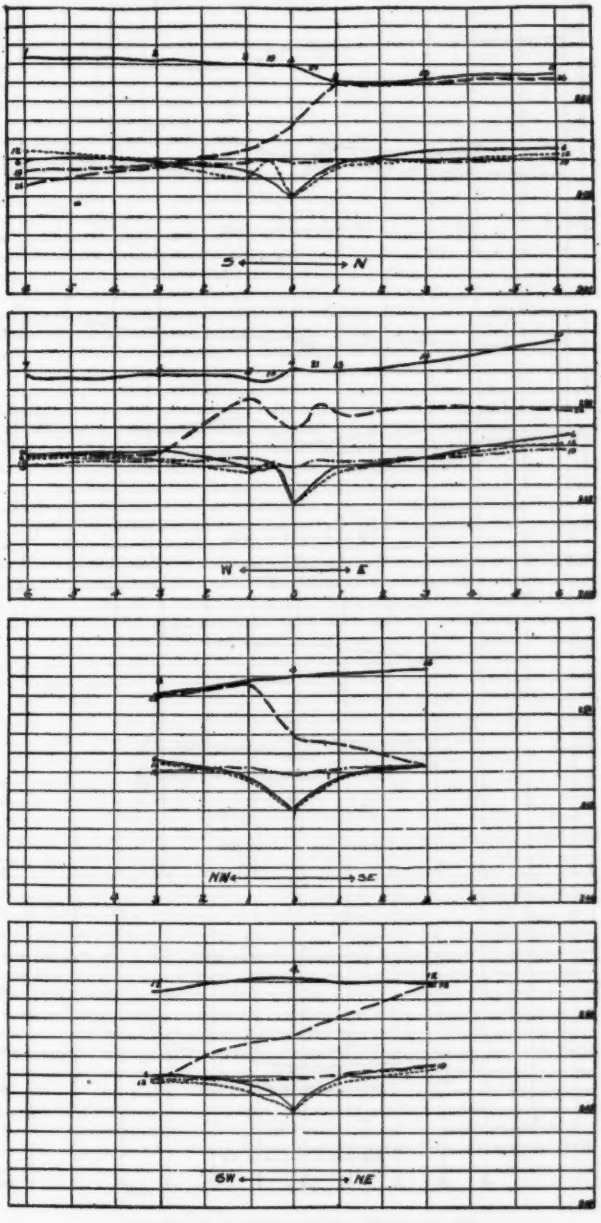

FIG. 13.—Profile of water table during July, 1915.

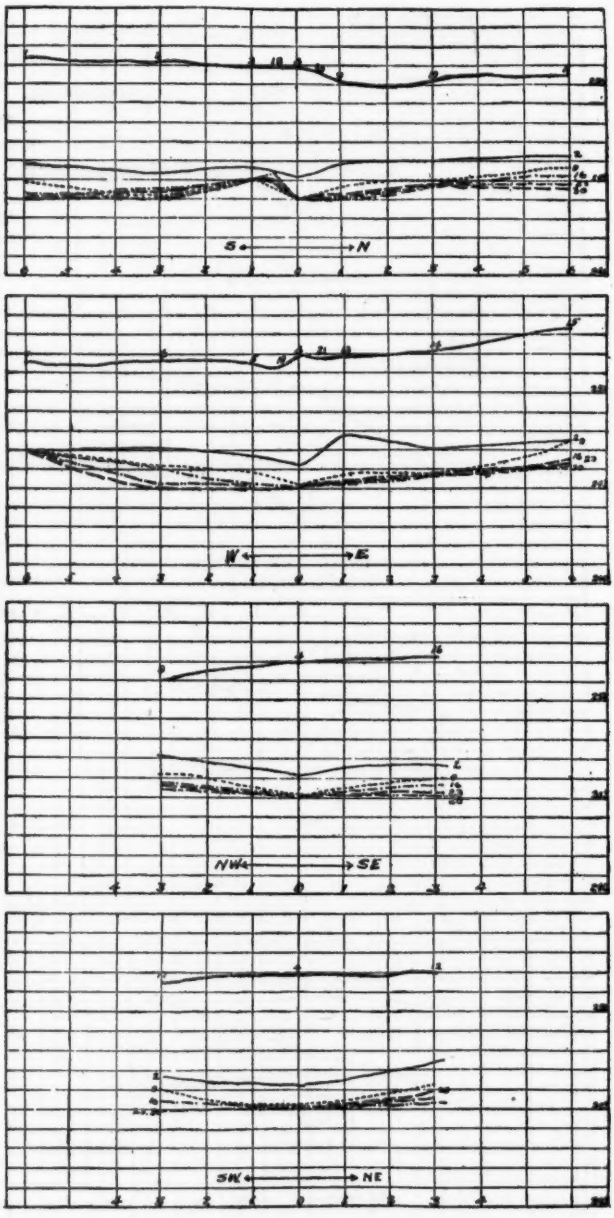

FIG. 14.—Profile of water table during August, 1915.

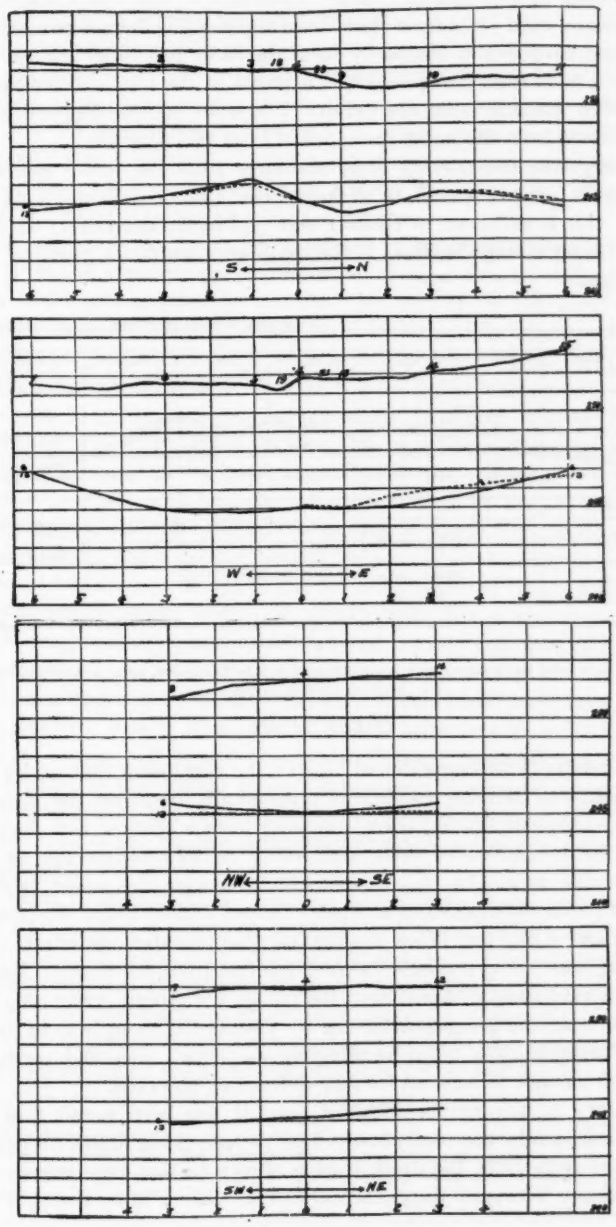

FIG. 15.—Profile of water table for September, 1915.

lower than that of March. After September 13 the water was everywhere more than 7 feet from the surface and could no longer be measured.

Figure 16 shows in composite form the same results as are shown in figures 2 to 8, each curve being a composite of the four well readings at the given distance from the pump. The wells on the diagonal at 300 feet distant from the pump are omitted from this diagram.

During May the average daily discharge from the pump was about 0.20 cubic feet per second, or slightly under 130,000 gallons per 24-hour day. This is sufficient to cover 1 acre 3¾ inches deep every 24 hours and without storage facilities is too small an amount for practical farm irrigation.

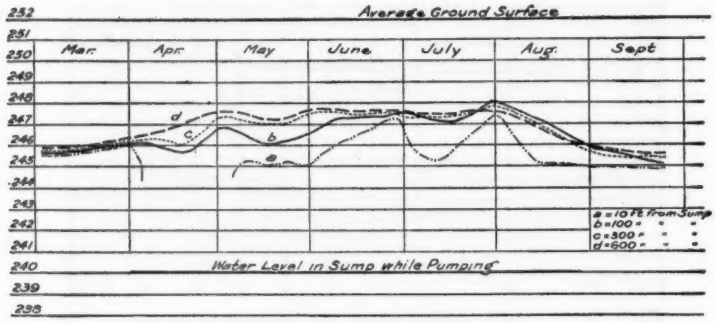

FIG. 16.—Composite curve showing water table from March to September, 1915, inclusive, at different distances from the pump.

CONCLUSIONS

The results of this experiment lead to the conclusion that under soil, irrigation, and farming conditions such as are found on the Kearney Park Experiment Station tract, pumping from a shallow well does not lower the ground-water table sufficiently to afford drainage to any considerable area. In this experiment, although the water table in the sump was maintained at a depth of about 12 feet below the ground surface and 5 to 7 feet below the normal ground water, the effect of the pumping was not appreciable beyond 100 feet from the pump. Except within a very short distance from the pump, the ground water rose to a point as near the ground surface in 1915 while the pump was in operation as it did in 1914, when no pumping was done. Seasonal variations are great enough to account for any differences observed.

Contrary to the results obtained here, it has been found that the water table can be materially lowered by the use of tile drains for greater distances away from the drain than is shown in this experiment. On the Kearney Vineyard Experimental Drain,[1] only 2 miles away, it was

[1] WEIR, W. W. PRELIMINARY REPORT ON KEARNEY VINEYARD EXPERIMENTAL DRAIN, FRESNO COUNTY, CALIFORNIA. Cal. Agr. Exp. Sta. Bul. 273, p. 101–123, 11 fig. 1916.

possible to keep the water table more than 2 feet lower at a distance of 160 feet from the drain than on surrounding untiled areas. This condition was obtained with the tile at a depth of less than 6 feet. On both the Dore tract[1] and the Toft-Hansen tract[2], about 6 miles from the Kearney Park experiment, the tile drainage systems had a noticeable effect on the ground-water table a mile away, although the tile were less than 5 feet deep on the Dore tract and only 3 feet deep on the Toft-Hansen tract. All of these drainage systems discharge into sumps from which the water is raised by means of pumps.

The fact that tile drains have proved more efficient than pumping from a well in lowering the ground-water table is due, no doubt, to the much larger area reached by the tile. No part of the 160 acres in the Kearney Vineyard Experimental Drain is more than 160 feet from a tile line, the Dore tract of 40 acres contains nearly 4,500 feet of tile, and there are 5,600 feet of tile on the 20-acre Toft-Hansen tract. Thus, with such a system any lateral movement of water is more readily intercepted, and any vertical pressure is relieved at more points than is possible where tile is not used, even though the water table is maintained at a greater depth in the well than is done by the tile lines. It would appear, therefore, from the results of these experiments that, although it has been proved feasible to reclaim water-logged land by means of tile drains, it would not be practicable to locate wells and pumping plants similar to the one described in this paper close enough together to lower the water table over any considerable area or develop enough water for practical farm irrigation without storage.

It is doubtful if the results of this experiment would have been materially different had it been located on the more poorly drained areas. Much the largest part of such areas about Fresno consists of soils mapped as belonging to the Fresno series. These soils contain hardpan layers nearer the surface, and the lateral movement of water is not so rapid as through soils of the Madera series such as are found on the experiment station tract.

In order to obtain the information given here, it was necessary to equip and operate a pumping plant for two years. The pump equipment, including sump, pump, motor, housing, power transmission, and discharge line, cost approximately $625. The power for the period covered by the experiment cost about $200, making a total of $825. There were some expenses incurred in installing test wells and making special investigations which would not be necessary under field conditions, and these have not been included in the total mentioned.

[1] FORTIER, Samuel, and CONE, V. M. DRAINAGE OF IRRIGATED LANDS IN THE SAN JOAQUIN VALLEY, CALIFORNIA. U. S. Dept. Agr. Office Exp. Stas. Bul. 217, 58 p., 8 fig, 2 pl. (maps). 1909.

[2] MACKIE, W. W. RECLAMATION OF WHITE-ASH LANDS AFFECTED WITH ALKALI AT FRESNO, CALIFORNIA. U. S. Dept. Agr. Bur. Soils Bul. 42, 47 p., 2 fig. 1907.

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